THE UNIVERSITY OF ALBERTA

AN INVESTIGATION OF THE STABILIZATION OF SEVERAL SANDS AND A SANDSTONE FROM ALBERTA USING PORTLAND CEMENT

A DISSERTATION
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF CIVIL ENGINEERING

by

Leonard Domaschuk

EDMONTON, ALBERTA

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THE UNIVERSITY OF ALBERTA

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The undersigned hereby certify that they have read and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "An Investigation of the Stabilization of Several Sands and a Sandstone From Alberta Using Portland Cement" submitted by Leonard Domaschuk in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

A soil which is generally considered inferior as a base course material, may be improved by the addition of portland cement. The mixture, known as soil-cement, possesses satisfactory characteristics and serviceability, as a base course material.

An investigation was made of the properties of soil-cement made from various sands found in the province of Alberta. The sands ranged from a fine silty sand to a crushed sandstone. The following are the results of the investigation:

1. There is a definite relationship between density and compressive strength of soil-cement. A small decrease in density is accompanied by a substantial decrease in compressive strength.
2. A time elapse between mixing and compacting the soil cement:
   (i) increases the compactive effort required to maintain a constant density.
   (ii) does not affect the compressive strength providing the density is kept constant.
   (iii) decreases the density and the compressive strength if the compactive effort is kept constant.
3. There appears to be some relationship between the uniformity coefficient of sands and the density-strength relationship of the soil-cement.
4. Breakdown of sandstone under compaction weakens the soil-cement.
5. The dry density of soil-cement increases with hydration

of the cement.

6. Fractured soil-cement regains compressive strength with time, if loading is discontinued.

A correlation of the properties of soil-cement produced in the field with that produced in the laboratory showed that:

1. The properties of the soil-cement produced in the laboratory can be duplicated in the field providing close control is exercised over gradation, cement content, and density.
2. Compressive strength can be used as the criterion of the soil-cement's ability to withstand exposure to the elements.

The various construction phases were evaluated.

Recommendations for further research were made.

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CHAPTER 1

INTRODUCTION

Soil-Cement, as the name implies, is a structural material formed by combining soil and portland cement, in proportions dependent on the soil type being utilized. It is a distinctive structural material having its own particular characteristics.* The physical properties of the soil, along with the physical and chemical properties of the cement, make up the physical characteristics of the soil-cement mixture.

Soil-cement is used primarily as a base course for roads, streets, and airport paving. In addition, it is used for: modification of soils, drainage ditch and canal linings, earth dam cores, facing for berms and dams, and many other uses. As a base course its strength is comparable to a weak concrete, but its composition and behaviour bears little resemblance to concrete. The cementing action of the cement is only effective if the mixture is compacted to a relatively high density. As a compacted, hardened, material it possesses rigidity and so acts like concrete in transmitting concentrated loads. However its behaviour is unlike that of concrete in that during hydration of the cement, the accompanying reduction in volume is greater than any subsequent volume change that might take place as the result of seasonal exposures to moisture, heat, or cold.* A primary function of the cement is to

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* Soil-Cement - A Construction Material - Catton, M.D.
Proceedings of the Conference of Soil-Stabilization
Massachusetts Institute of Technology

minimize volume changes brought about by variations in temperature and moisture. If a considerable volume change takes place, there is a breakdown of the cementing bond between particles causing the structural material to revert to the original state.

Soil-cement was introduced by Dr. J. H. Amies of the United States as a low cost paving material in 1917. At the time it was known as Soilamine. In 1935 the Portland Cement Association initiated a comprehensive program of investigations, tests and development, in an attempt to establish predictable factors that could be used as basis for design, construction control, and use of soil-cement. In that year there were nineteen thousand square yards of soil-cement used in roadway construction in the United States.[*] Its use as a construction material rose steadily up till the year 1942 after which there was a decline during the war years. In the years following 1945 the quantity used per year increased and in 1954 twenty million square yards of soil-cement were placed. By 1955 a total of 161 million square yards of soil-cement had been used in the United States as a construction material in streets, airport and highway paving and other miscellaneous projects. In some instances it was used as a surfacing material but its primary use was as a base-course. Every state in the United States had made use soil-cement to some degree with the State of California recording the highest percentage, followed by Louisiana and North

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* Summaries of Soil-Cement Construction
SC-104 1955 Supplement
Portland Cement Association

Carolina.

In Canada, the use of soil-cement as a roadway construction material has been recent and limited. It is only in the past few years that any soil-cement projects have been undertaken and they were primarily experimental.

In 1959 the Alberta Provincial Department of Highways undertook Canada's largest soil-cement project. Approximately fifty miles of roadway construction was started in which soil-cement was used as a base course. The soil ranged from a fine silty sand to a crushed sandstone. Since this was the Department's first substantial soil-cement project, it was considered advisable to analyze the problems associated with the design and construction of soil-cement peculiar to the climate and materials of the province. Consequently, in conjunction with the Alberta Research Council and the University of Alberta, provision was made for an investigation of the problems relating to the use of soil-cement in the Province of Alberta.

CHAPTER 2

SOIL-CEMENT DESIGN TESTS AND CRITERIA ESTABLISHED BY THE PORTLAND CEMENT ASSOCIATION

The primary purpose of laboratory tests associated with the design of soil-cement is to establish:

1. The minimum cement content that must be added to the soil to ensure a soil-cement mixture that will withstand the forces of expansion and contraction.
2. The amount of water that should be added to the mix.
3. The density to which the mixture should be compacted.

The following is a general description of the tests used in the design of soil-cement.

MOISTURE-DENSITY RELATIONSHIP*

The Standard Proctor density test is used to establish the optimum moisture content and the maximum density of the soil-cement mixture.

WET-DRY TEST**

The wet-dry test is used as a measure of the ability of the soil-cement mixture to withstand shrinkage and expansion stresses.

Soil-cement specimens are formed in Standard Proctor

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* Method of Test for Moisture-Density Relations of Soil-Cement Mixtures
A.S.T.M. Designation D 558-44

** Method of Wetting and Drying Test of Compacted Soil-Cement Mixtures
A.S.T.M. Designation D 558-44

molds at optimum moisture content and maximum density. The specimens are removed from the molds and allowed to moist-cure for seven days. They are then subjected to twelve cycles of wetting and drying. Soaking the specimens for five hours in water at room temperature constitutes the "wetting" while drying the specimens in an oven at 71°C for 42 hours constitutes the "drying" portion of the cycle. The "drying" sets up high shrinkage stresses in the specimens. Upon wetting, the stresses are released and high surface expansion stresses occur. The effect of these stresses is to destroy some of the bond between the soil particles. The degree to which this occurs is measured by brushing the specimen with a standard scratch brush in a specified manner. The amount of material thus removed is determined and constitutes the soil-cement loss. It is expressed as a percentage of the original mass. The specimens are brushed after each cycle and the total soil-cement loss is compared with a critical value.[*] The critical value of soil-cement loss depends upon the soil type. It was established by subjecting specimens which had undergone the wet-dry (or freeze-thaw) test to actual weathering forces. Its ability to resist the stresses set up by severe variations in moisture and temperature was correlated with the soil-cement loss following the twelve cycles of wet-dry (or freeze-thaw) test.

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* Table 1 Appendix 1

FREEZE-THAW TEST*

The freeze-thaw test is used as another measure of the soil-cement's ability to resist shrinkage and expansion. The specimens are prepared in a manner identical to that of the wet-dry test. After the seven day curing period, the specimens are subjected to twelve freeze-thaw cycles. The cycle consists of placing the specimens in a refrigerator (-23°C) for 24 hours, and then removing the specimens and allowing them to thaw in a moist room (humidity greater than 90 percent, temperature + 70°F) for 23 hours. Provision is made to allow the specimens to absorb water by capillarity during the thawing period.

The soil-cement is subjected to high expansion stresses as the water in the voids freezes. The accompanying loss in particle bond is measured by brushing the specimens and determining the soil-cement loss in a manner similar to that used for the wet-dry test. The total soil-cement loss is then compared with the critical value.

SUPPLEMENTARY TESTS

Compressive-Strength Tests

Soil-cement specimens are formed in Proctor molds at optimum moisture content and maximum density, and are allowed to moist cure. Their two, seven, and twenty-eight day compressive strengths are then determined. Prior to breaking the specimens are capped and allowed to soak for four hours.

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* Method of Freezing and Thawing Test of Compacted Soil-Cement Mixtures
A.S.T.M. Designation D 560-44

The criteria for compressive-strength tests is that the compressive strength should increase as the age of the soil-cement increases.

Organic Test

Research on soil-cement involving organic soils has shown that there is a definite tendency for the cement requirement to increase as the calorimetric reading of the soil increases.* However, there are sufficient exceptions to this and for this reason the test is not routine. The "wet-dry" or "freeze-thaw" tests indicate whether the soil-cement containing organics will harden satisfactorily.

Cement Content

As a check on the uniformity of mix, the cement content of mixed material may be obtained by a chemical analysis.** The test may be used to establish the required duration of mixing time to ensure a uniform dispersing of the cement throughout the soil.

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* Calorimetric reading is determined by a procedure essentially the same as the Test for Organic Impurities in Sands for Concrete
A.S.T.M. Designation C 40-48

** Cement Content of Soil-Cement Mixtures
A.S.T.M. Designation D 806-57

CHAPTER 3

DESIGN

General Procedure for the Design of Soil-Cement

The first step in designing soil-cement is to select a minimum cement content that will enable the mixture to withstand exposure to the elements. Since the soil constitutes approximately ninety percent of the soil-cement mixture, its characteristics determine almost exclusively the cement requirement. As a general rule the cement requirement increases as the silt and clay content increases.[☆] An exception to this is one-sized sand having little or no silt or clay content.[☆☆] The Portland Cement Association carried out a comprehensive investigation of the cement requirement for various soil groups. The usual range in cement requirement for various A.A.S.H.O. soil groups is given in Table 2, Appendix I. Thus the first step is to classify the soil according to the A.A.S.H.O. soil classification system and to select an estimated cement content on the basis of the classification.

A moisture-density test is then carried out at the preliminary estimated cement content.

Wet-dry and freeze-thaw test specimens are then molded at the estimated cement content and at cement contents two percent above and below, that cement factor.

The soil-cement loss as the result of the wet-dry and freeze-thaw tests is determined and compared with the criteria for that particular soil type.

☆ Soil-Cement Laboratory Handbook PCA SC6-4 (1956)

☆☆ Ibid

The minimum cement content which enables the mixture to satisfactorily withstand the disruptive shrinkage and expansion forces, is selected as the cement requirement.

Short Cut Test Procedure For Sandy Soils

A short-cut procedure has been established for sandy soils by the Portland Cement Association. It is based on the result of a correlation made of test data obtained by testing 2229 sandy soils. It is designed to minimize the amount of work normally required in the design of soil-cement. The procedure is only applicable to soils containing less than fifty percent silt and clay-size material smaller than 0.05 mm, and less than twenty percent clay-size material smaller than 0.005 mm. The grain-size criteria is not applicable to soils containing a high percentage of organics, or miscellaneous granular materials. Such soils must undergo the normal test procedure.

The only laboratory tests required are, a grain-size analysis, moisture-density test, and compressive strength tests. The procedure has been found to provide a safe cement factor generally close to that indicated by wet-dry and freeze-thaw tests.

A detailed description of the procedure is given in Appendix I.

Design of the Soil-Cement Mixtures

It was anticipated that the following borrow pits would be used in the proposed construction.

Project 12-B-1 and 2

1. Elhardt Pit

   Fine Silty Sand

2. Slemp Pit

   Fine Sand

3. Ray Long Pit

   Medium to Fine Silty Sand

4. Ravenshaw Pit

   Fine Silty Sand

Project 2-K-2

1. Reaume Pit

   Fine to Medium Sand

2. Updike Lake Pit

   Crushed Sandstone (minus two inch)

3. Albright Creek Pit

   Crushed Sandstone (minus two inch)

Project 28-B-2

1. Sheppart Pit

   Fine to Medium Sand

The following procedure was used by the Provincial Highway Department to determine the cement requirement for the above soils.

See Plate 35 Appendix I for grain size distribution curves

The Short-cut Test Procedure for sandy soils was used to obtain a tentative cement content. Specimens were then molded at maximum density and optimum moisture content, at the tentative cement content and at cement contents two percent above and below the tentative value. Some of the specimens were used to determine a seven day control compressive strength, while others were subjected to twelve freeze-thaw cycles. The compressive strengths of the specimens which had undergone the freeze-thaw cycles were then determined and compared to the control strengths. The cement content at which there was little or no loss in compressive strength as a result of the freeze-thaw action, was selected as the cement requirement. Summary sheets showing the soil-gradation and classification, the cement content as determined by the Short-cut Test Procedure, and the above procedure, are included in Appendix I.

The cement requirement for the soils was also determined at the Portland Cement Association laboratory. The values are included in the summary sheets. The soil-cement loss as determined by the freeze-thaw test was used as the criteria by the Portland Cement Association.

CHAPTER 4

LABORATORY INVESTIGATION

At the time the author undertook the investigation, the Department of Highways had their testing program under way and had arrived at tentative cement requirements. In addition, the specifications governing the construction of the soil-cement base course had been drawn up. The possible variations in the engineering properties of the soil-cement as placed in the field, with that produced in the laboratory, were investigated on the basis of the construction specifications. The phases investigated were:

1. The effect of lowering the density from 100 to 95 percent standard Proctor on the compressive strength of the soil-cement. According to the specifications, the minimum acceptable field density was 95 percent standard Proctor. All design tests had been conducted on specimens molded at 100 percent standard Proctor.
2. The effect of elapsed time between mixing and final compaction, on the compressive strength and the density. Specifications permitted an elapsed time of two hours.
3. The effect of varying the uniformity coefficient of a sand, without altering its soil classification, on the compressive strength of the soil-cement.
4. The amount of breakdown of the sandstone under compaction.

Other phases investigated were:

5. The increase in dry density brought about by hydration of the cement.
6. The ability of the soil-cement to regain strength, after it has been fractured.

Strength versus Density

To determine the effect of lowering the density from 100 to 95 percent standard Proctor, on the compressive strength, the following procedure was used.

Compressive strength specimens were molded in groups of three, at densities ranging from approximately 85 to 110 percent standard Proctor. The three specimens of a group were molded at the same density and four groups were used to cover the density range. The following compactive effort was applied to each group respectively; 5 blows, 10 blows, 25 blows and 50 blows per layer.

The seven day compressive strength of the specimens was determined.[1] The average dry density and compressive

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1. In computing the compressive strength the l/d ratio was taken into consideration. Normally this is not done if all specimens are of identical size, since only relative values are of concern. However there were many instances during the investigation in which the specimens were of a size other than that of the Proctor mold, and so it was necessary to reduce all compressive strengths to a common basis. Since soil-cement fails in a manner similar to that of concrete (double-cone), the l/d correction factor for concrete specimens was used in computing the compressive strengths. The correction factors were taken from the Design and Control of Concrete Mixtures Manual.*

Note: All subsequent compressive strengths have been corrected for the l/d ratio unless otherwise specified.

* Design and Control of Concrete Mixtures 9th. Edithion (1950)

strength of each group was computed. Dry density versus seven day compressive strength was then plotted using the average values.

The above procedure was carried out at the tentative cement content and at cement contents two percent above and below the tentative values. The density-strength relationship was determined in this manner for six soils. Larger specimens were used for the Updike Lake material to incorporate the minus two inch sandstone. The specimens were formed in standard concrete molds, and the material was placed in two, three inch lifts. It was compacted with a Marshall compacting hammer and the number of blows per layer was the same as had been used for the other soils.

The density-strength relationship of the various soil-cement mixtures investigated, is given by Plates 1 to 6.

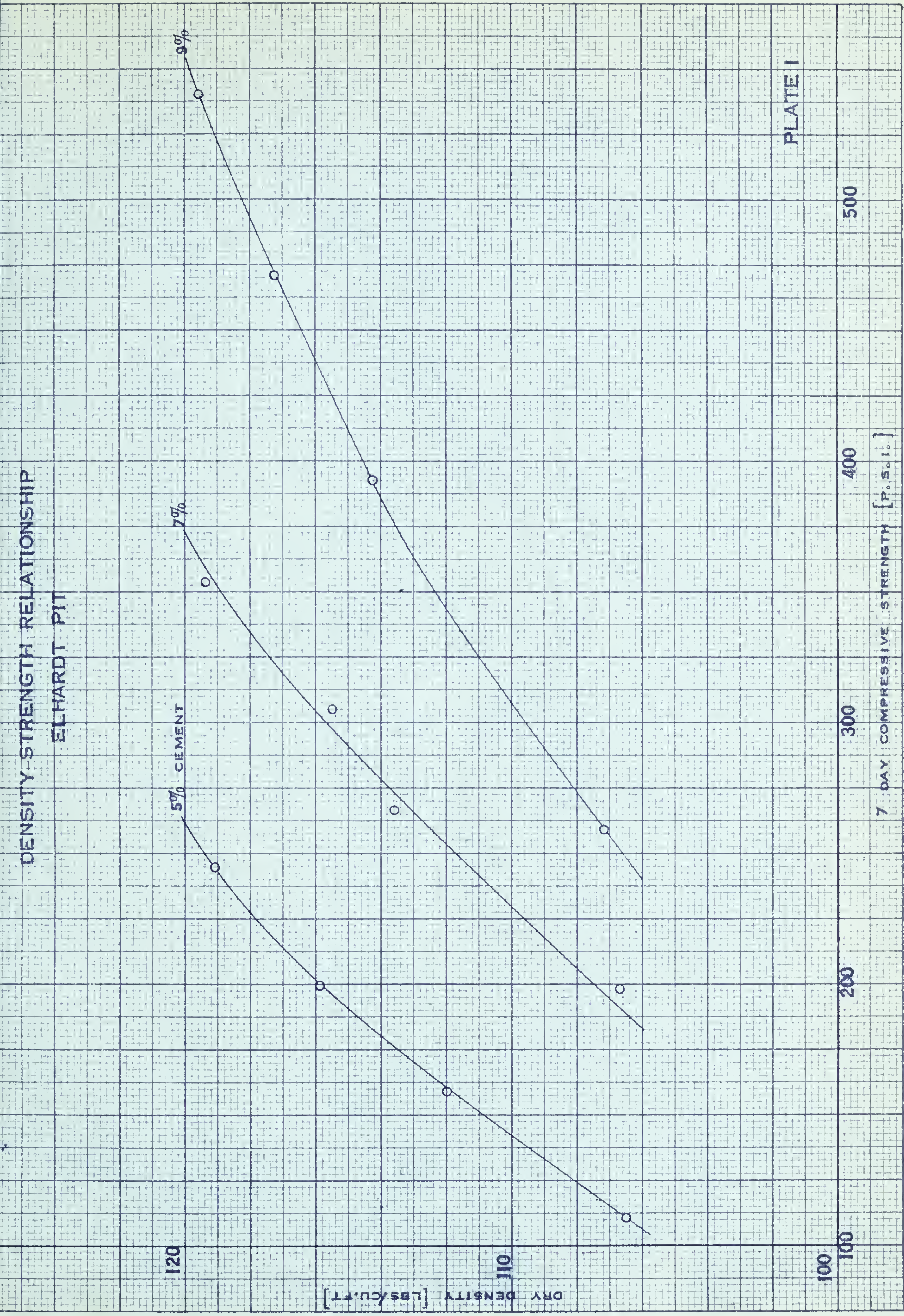
According to the specifications the maximum deviation in cement content permitted, was two percent above or below the design value. To illustrate the range of compressive strengths that could be expected in the field, a plot of compressive strength versus cement content for a density range of approximately 90 to 100 percent standard Proctor was drawn up. Such plots are illustrated by Plates 1a to 6a. Standard Proctor (SP), and 95 percent standard Proctor curves, are included on these plots.

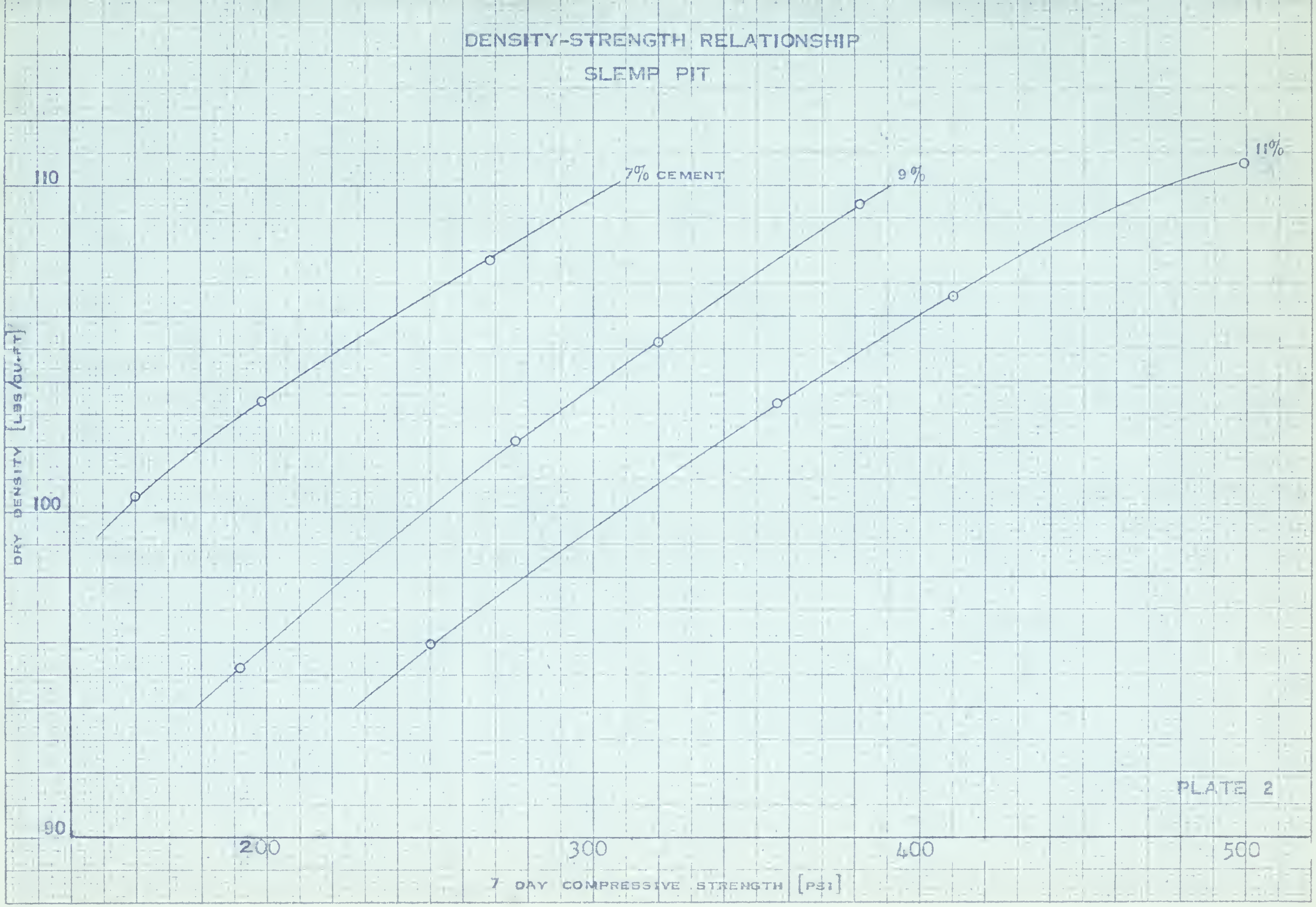
The seven day compressive strengths corresponding to the following were taken from the above plots and tabulated. (Table 3)

1. Standard Proctor density and design cement content.

2. Ninety-five percent standard Proctor density and design cement content.
3. Ninety-five percent standard Proctor and minus two percent of the design cement content.

The deviations in compressive strength from the design value (item 1) are also given in Table 3.


DENSITY-STRENGTH RELATIONSHIP
ELHARDT PIT
PLATE I
5% CEMENT
7%
9%
7 DAY COMPRESSIVE STRENGTH [P.S.I.]
100
200
300
400
500
DRY DENSITY [LBS/CU.FT]
100
110
120


DENSITY-STRENGTH RELATIONSHIP
SLEMP PIT
7% CEMENT
9%
11%
110
100
90
DRY DENSITY [LBS/CU.FT]
200
300
400
500
7 DAY COMPRESSIVE STRENGTH [PSI]
PLATE 2

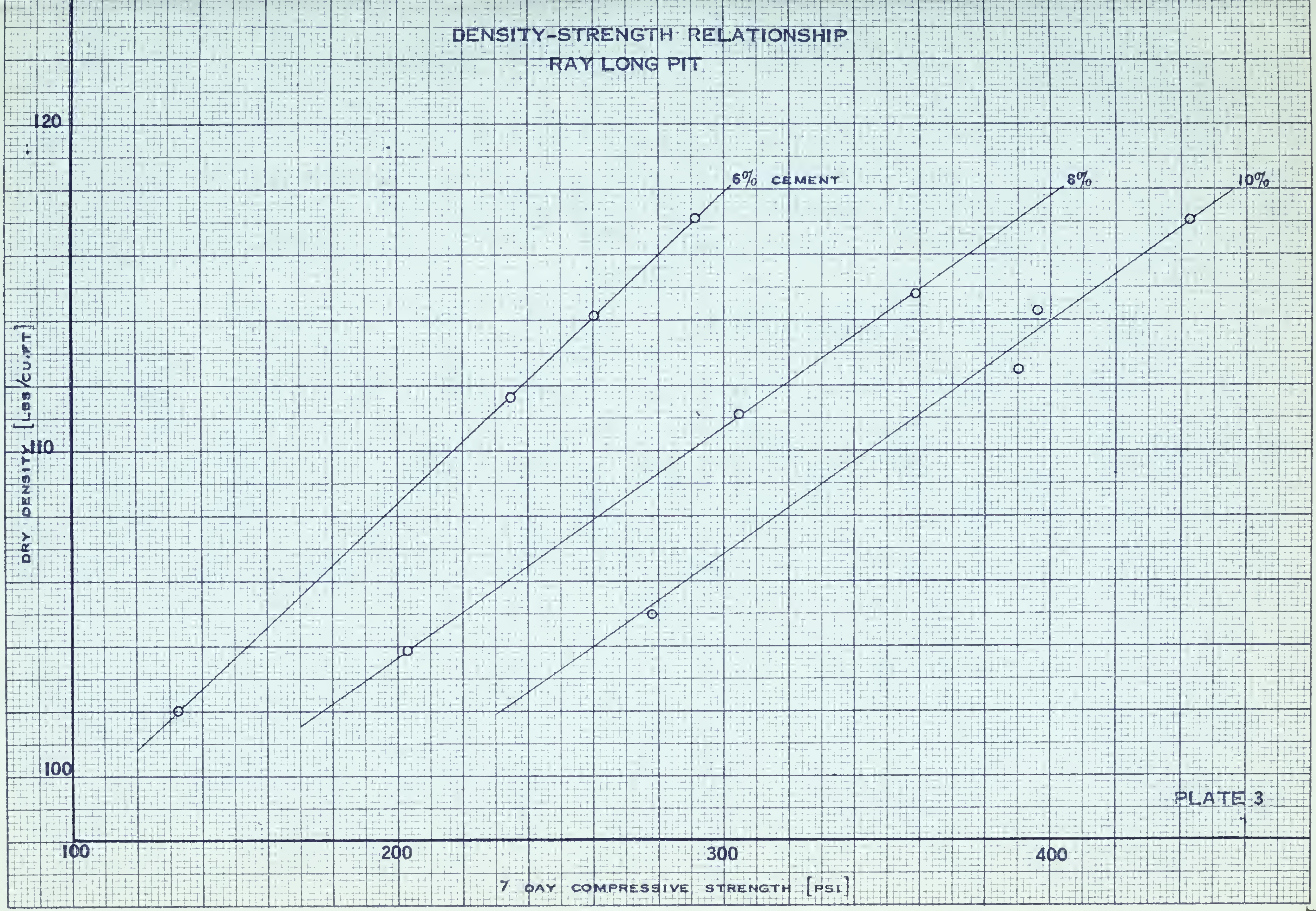
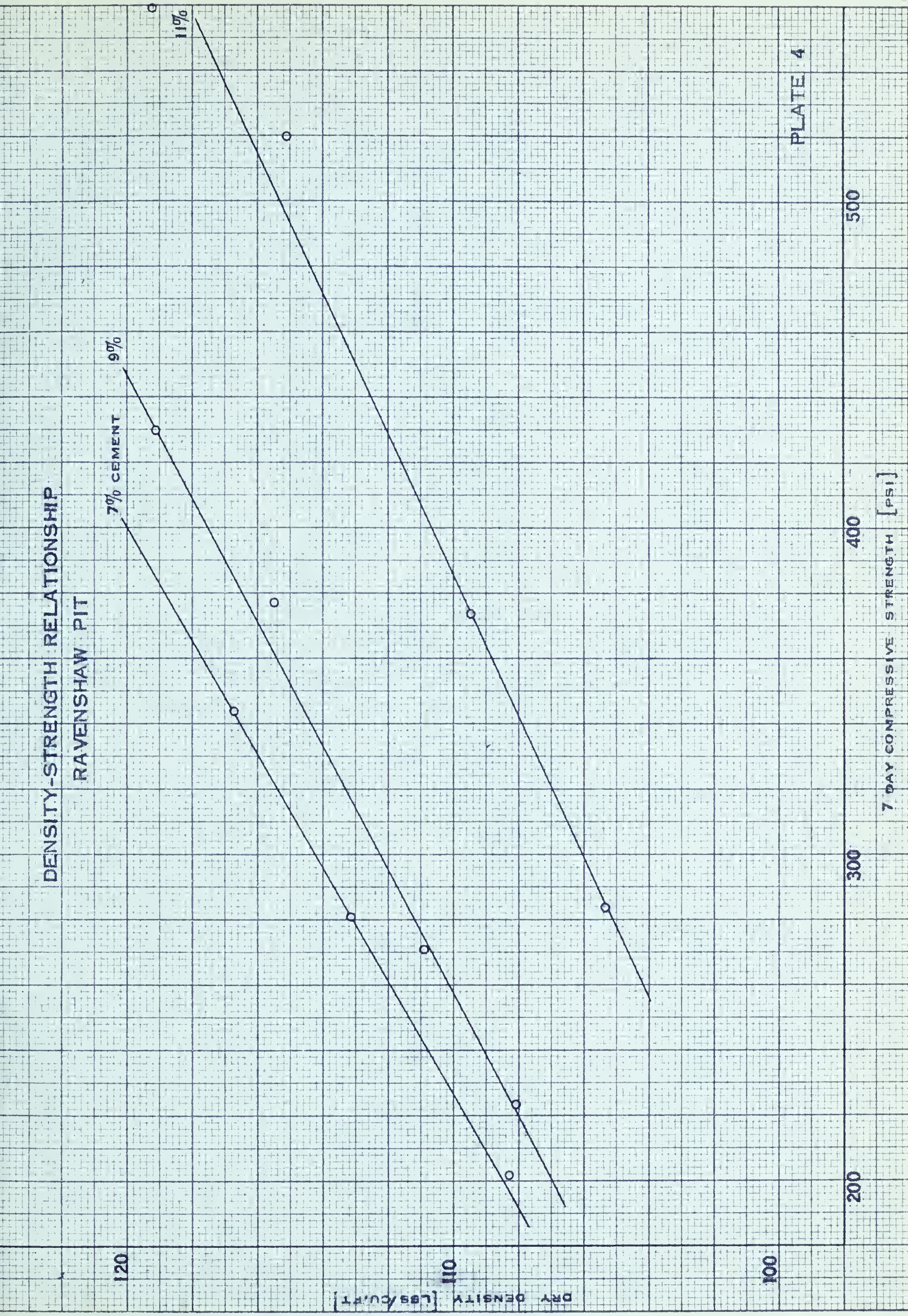
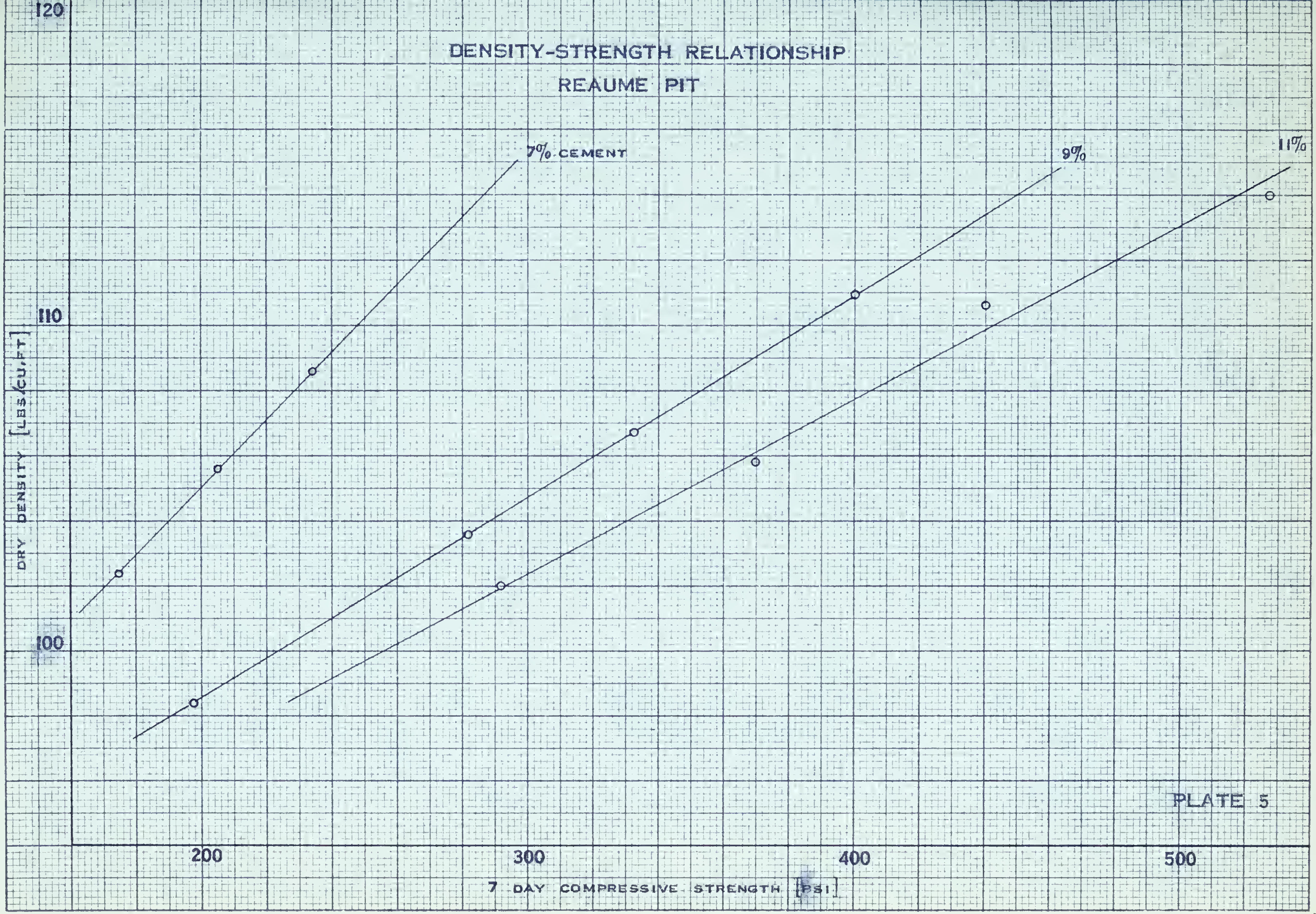
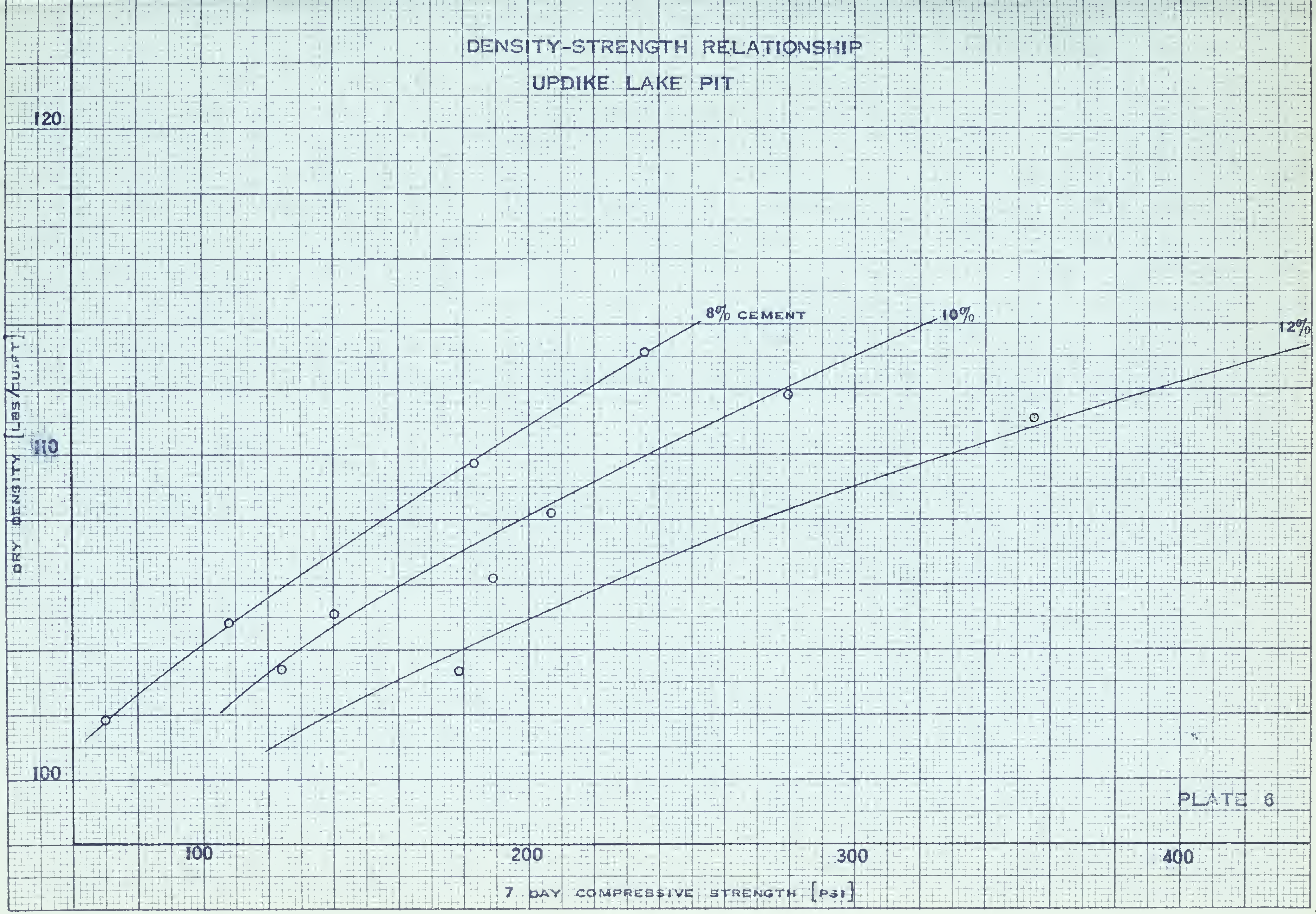
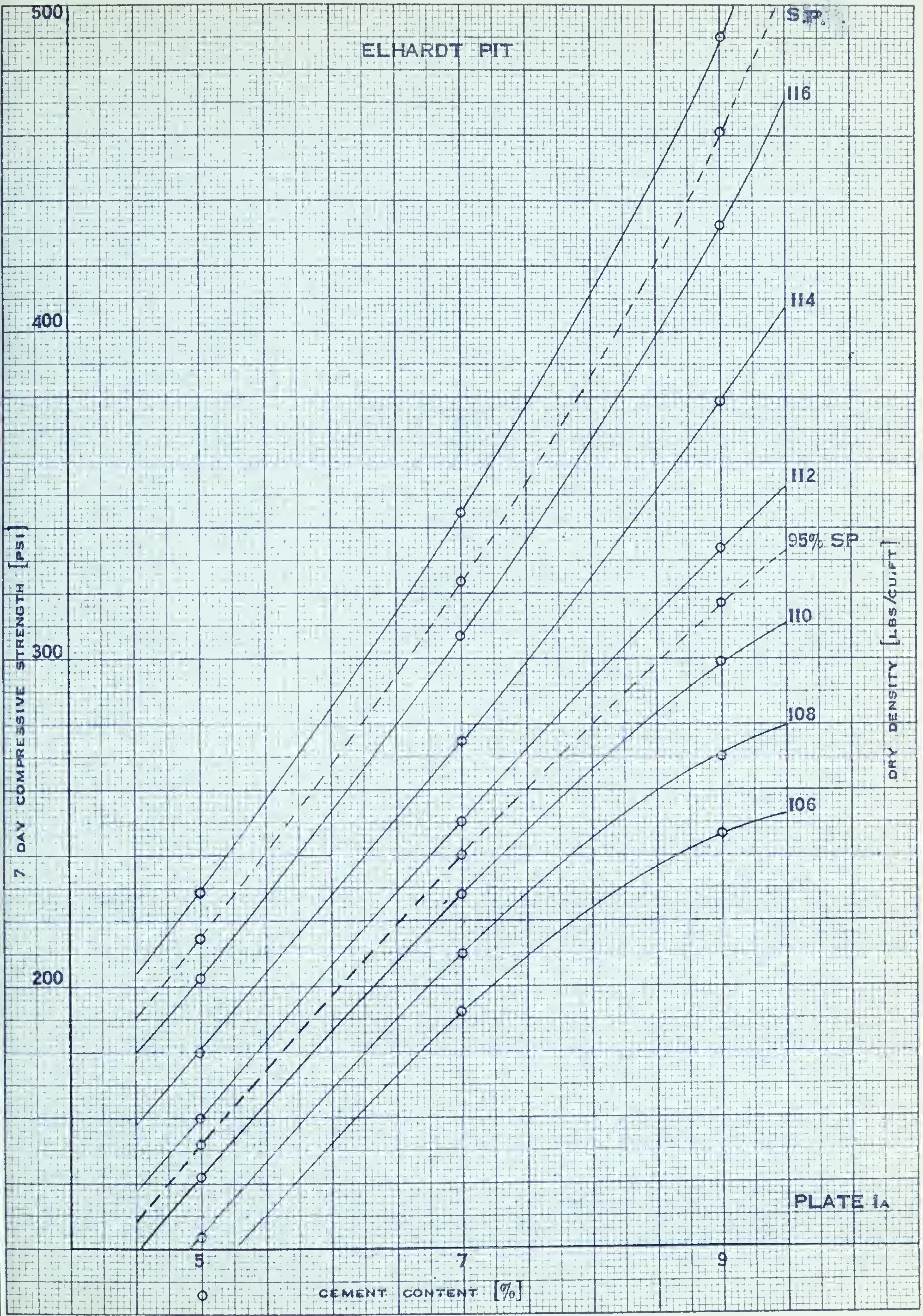

DENSITY-STRENGTH RELATIONSHIP
RAY LONG PIT
6% CEMENT
8%
10%
120
110
100
DRY DENSITY [LBS/CU.FT.]
100
200
300
400
7 DAY COMPRESSIVE STRENGTH [PSI]

PLATE 3

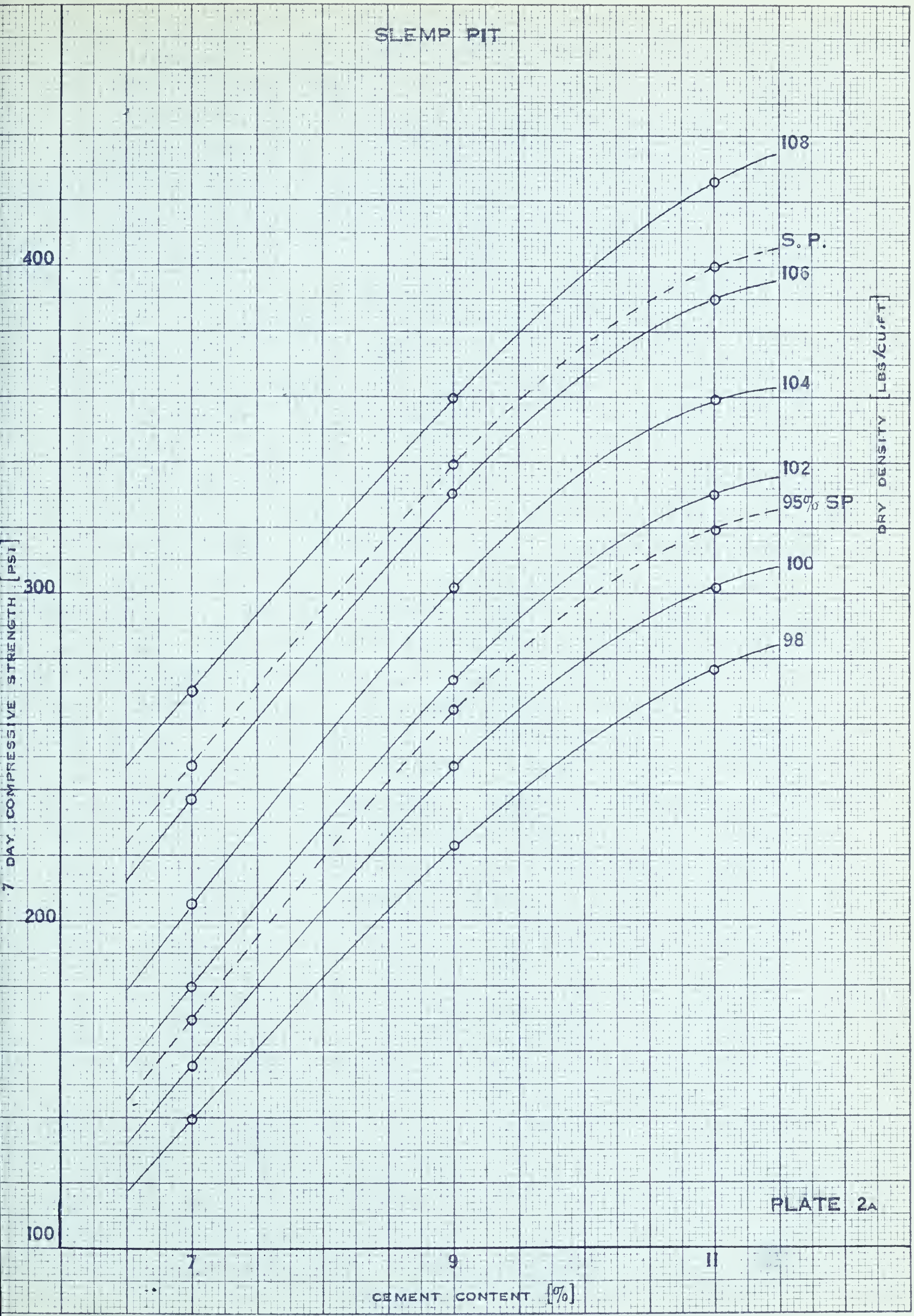

DENSITY-STRENGTH RELATIONSHIP
RAVENSHAW PIT
PLATE 4
7% CEMENT
9%
11%
DRY DENSITY [LBS/CU.FT]
120
110
100
7 DAY COMPRESSIVE STRENGTH [PSI]
200
300
400
500


DENSITY-STRENGTH RELATIONSHIP
REAUME PIT
7% CEMENT
9%
11%
120
110
100
DRY DENSITY [LBS/CU.FT]
200
300
400
500
7 DAY COMPRESSIVE STRENGTH [PSI]
PLATE 5


DENSITY-STRENGTH RELATIONSHIP
UPDIKE LAKE PIT
8% CEMENT
10%
12%
120
110
100
DRY DENSITY [LBS/CU.FT]
100
200
300
400
7 DAY COMPRESSIVE STRENGTH [PSI]
PLATE 6



ELHARDT PIT
500
400
300
200
7 DAY COMPRESSIVE STRENGTH [PSI]
S.P.
116
114
112
95% SP
110
108
106
DRY DENSITY [LBS/CU.FT]
5
7
9
CEMENT CONTENT [%]
PLATE 1A


SLEMP PIT
108
S. P.
106
104
102
95% SP
100
98
400
300
200
100
7 DAY COMPRESSIVE STRENGTH [PSI]
DRY DENSITY [LBS/CU.FT]
7
9
11
CEMENT CONTENT [%]
PLATE 2A

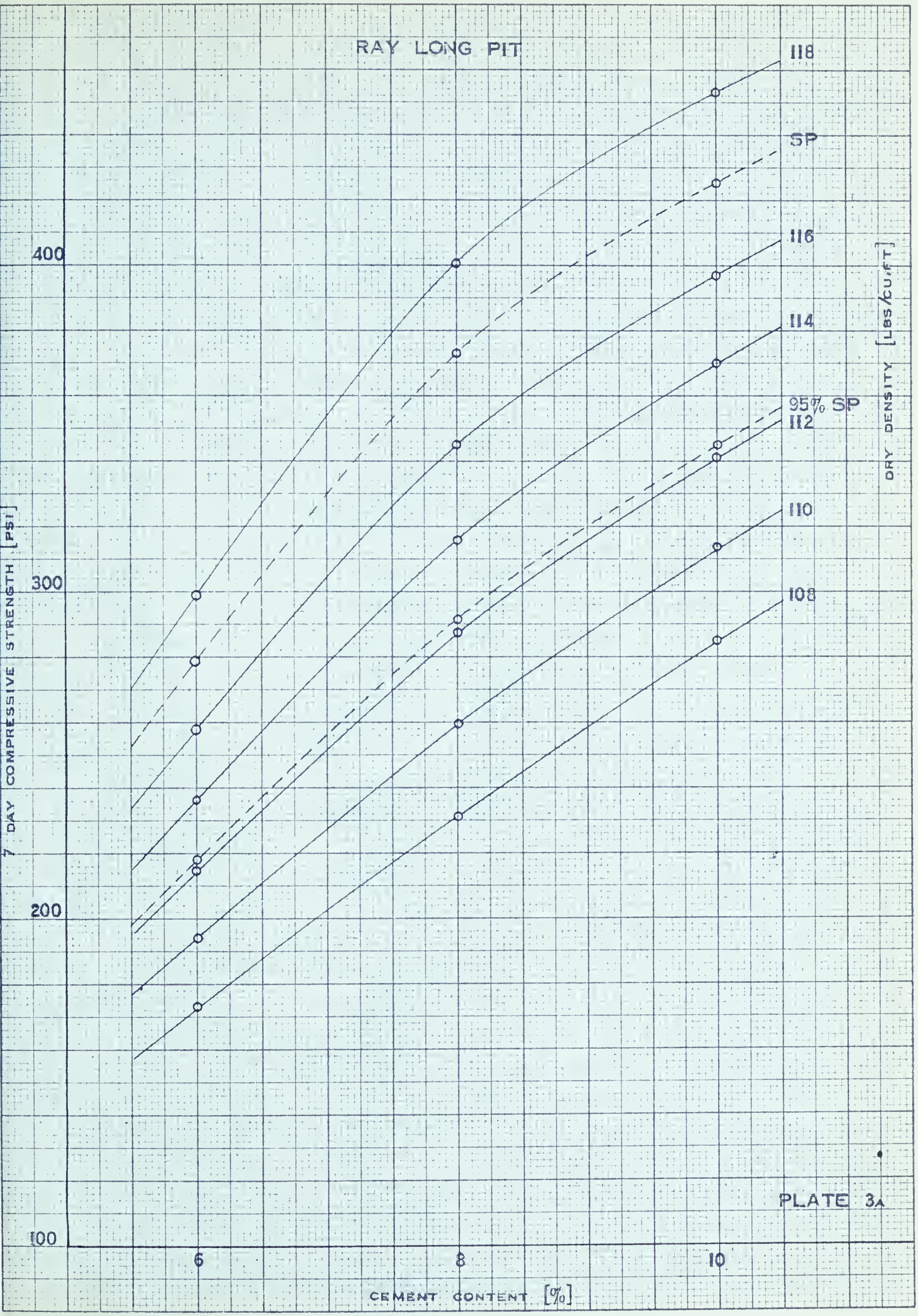
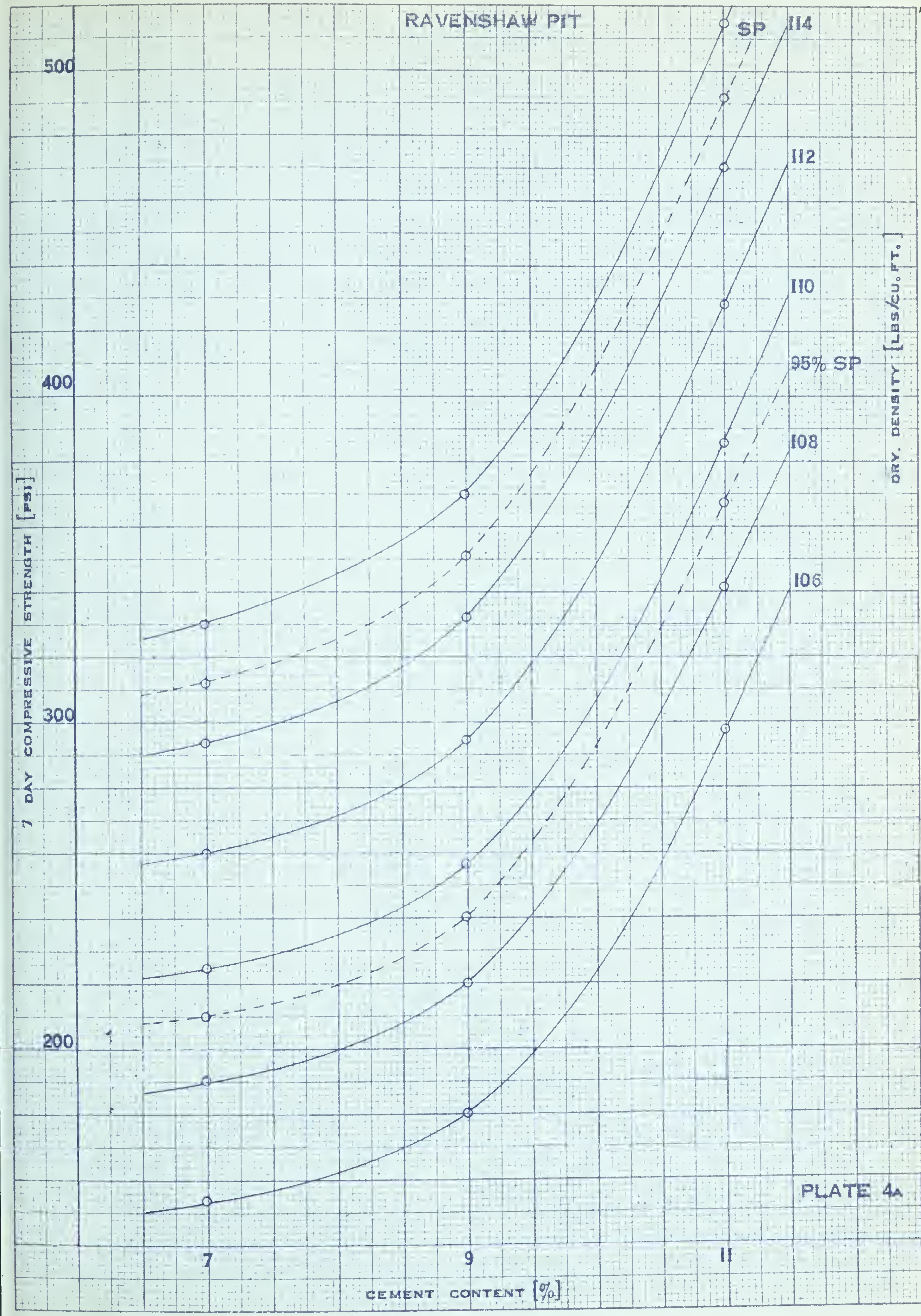

RAY LONG PIT
118
SP
116
114
95% SP
112
110
108
DRY DENSITY [LBS/CU.FT]
7 DAY COMPRESSIVE STRENGTH [PSI]
400
300
200
100
6
8
10
CEMENT CONTENT [%]

PLATE 3A


RAVENSHAW PIT
SP
114
112
110
95% SP
108
106
500
400
300
200
7 DAY COMPRESSIVE STRENGTH [PSI]
DRY. DENSITY [LBS/CU. FT.]
7
9
11
CEMENT CONTENT [%]
PLATE 4A

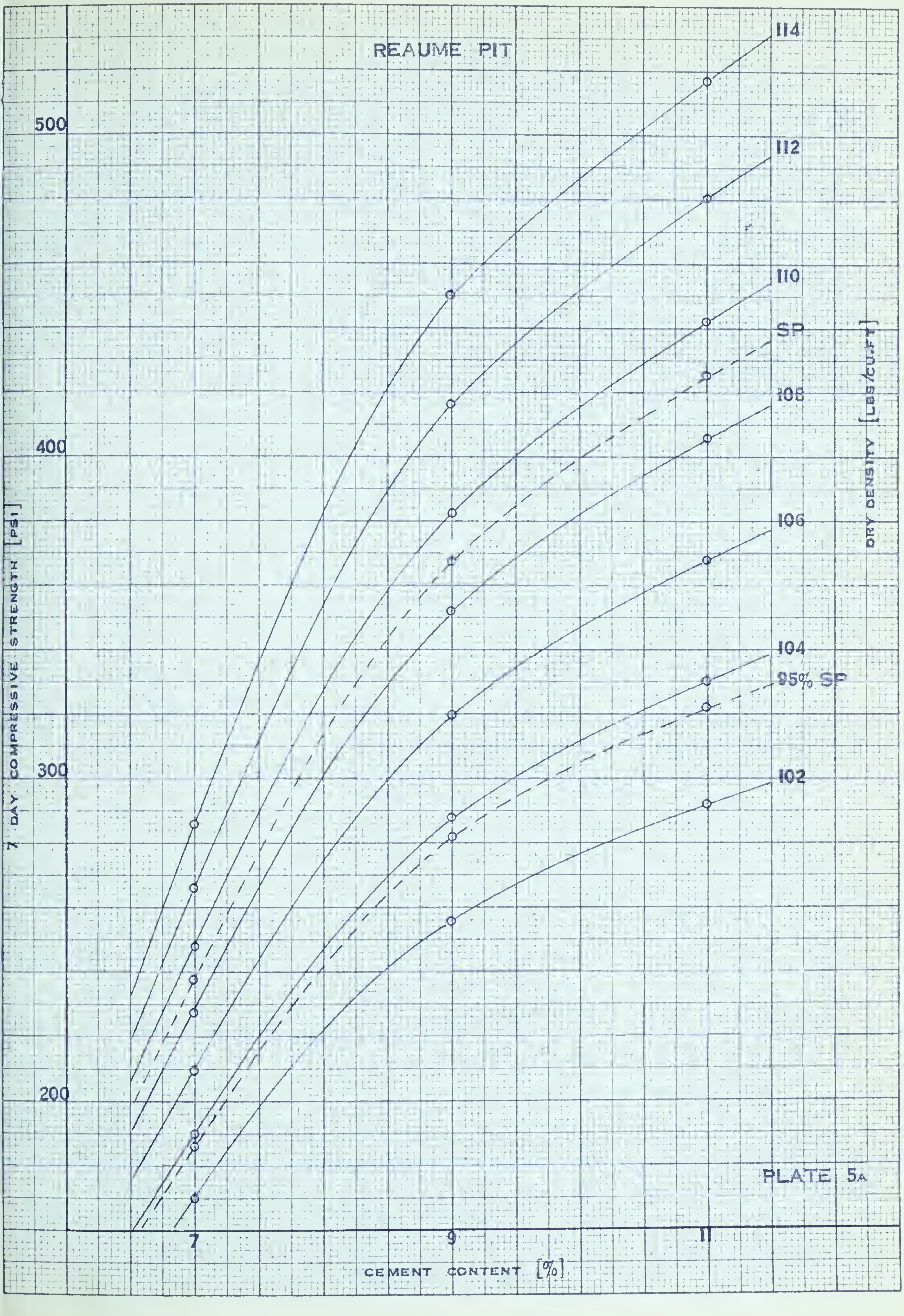

REAUME PIT
500
400
300
200
7 DAY COMPRESSIVE STRENGTH [PSI]
114
112
110
SP
108
106
104
95% SP
102
DRY DENSITY [LBS/CU.FT]
7
9
11
CEMENT CONTENT [%]

PLATE 5A

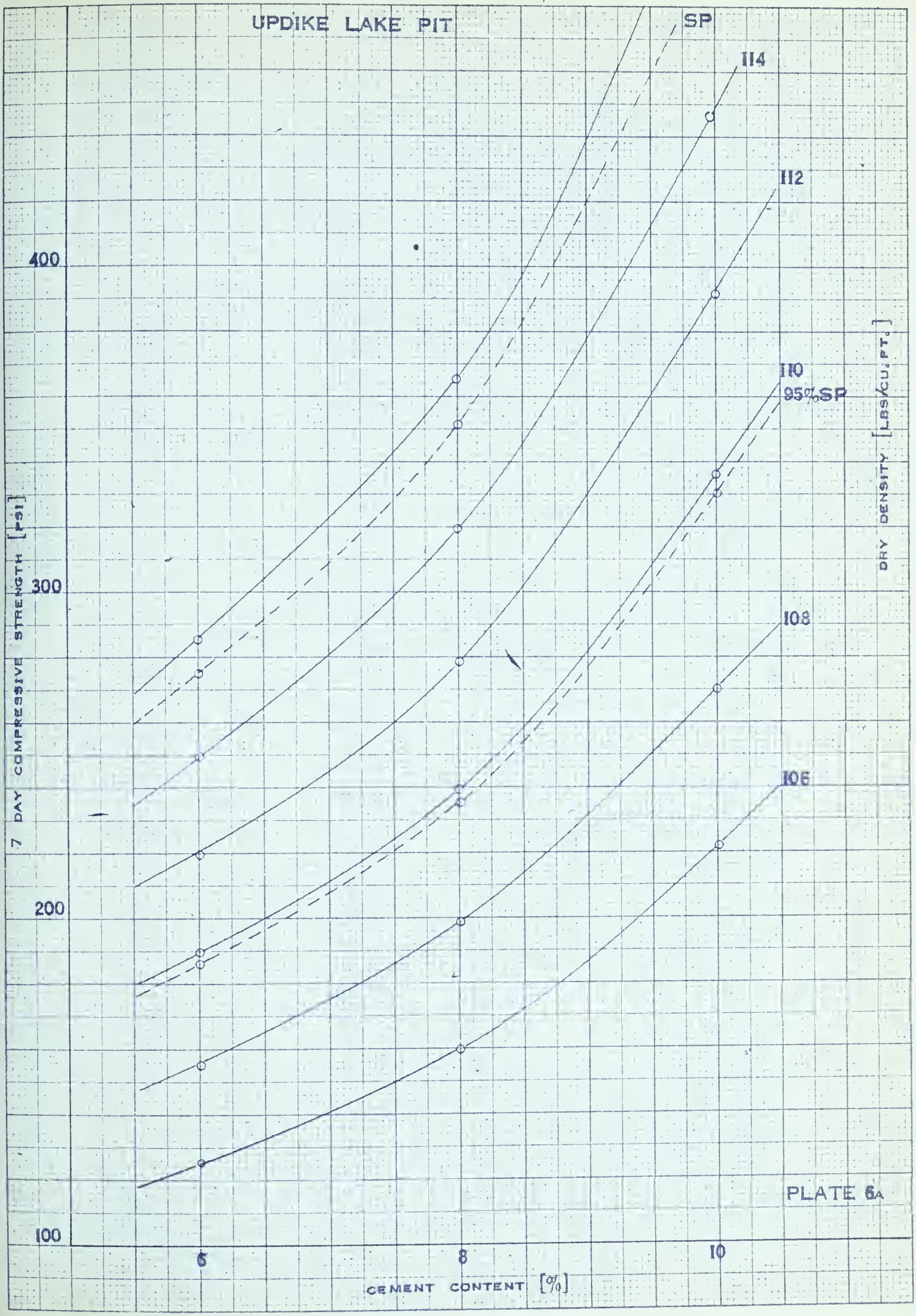

UPDIKE LAKE PIT
SP
114
112
110
95%SP
108
106
400
300
200
100
6
8
10
7 DAY COMPRESSIVE STRENGTH [PSI]
DRY DENSITY [LBS/CU. FT.]
CEMENT CONTENT [%]

PLATE 6A

TABLE 3

LOSS IN COMPRESSIVE STRENGTH DUE TO DECREASE IN DENSITY

SUMMARY SHEET

Pit	Comp. Str.(psi)@ Design % Cement Std. Proct.	Comp. Str.(psi)@ Design % Cement 95% Std. Proct.	% Loss	Comp.Str.(psi) @ 95% Std. Proct. and -2% Cement	% Loss
Elhardt	324	240	26	152	53
Slemp	340	264	22	170	50
Ray Long	374	292	22	218	42
Ravenshaw	368	256	30	226	39
Reaume	329	240	27	164	50
Updike Lake	352	236	33	186	47

The plots of seven day compressive strength versus dry density (Plates 1 to 6), indicated a definite relationship between the strength and density of the soil-cement. A small decrease in density brought about an appreciable loss in compressive strength. The magnitude of loss in strength per unit decrease in density, as indicated by the slope of the curves, varied with the material and the cement content. In most instances the density-strength relationship was linear on an arithmetic plot.

The only curves which deviated appreciably from a straight line relationship were those corresponding to the Elhardt material.

Although all the soils investigated, with the exception of the Updike Lake sandstone, were of the same soil-classification (A-2-4), their density-strength relationships differed. This indicates that an equation for the density-strength relationship cannot be derived for a general soil type. This also points out, that the cement requirement can not be selected on the basis of soil-classification alone.

Plates 1a to 6a illustrate the range in compressive strengths that might be expected with a five percent variation in density (95 to 100 percent Proctor) and a two percent variation in cement content. The loss in compressive strength corresponding to a decrease in density from 100 to 95 percent Proctor and at the design cement content, ranged from 22 to 33 percent. The loss corresponding to a five percent decrease in density and a two percent decrease in cement content, ranged

from 39 to 53 percent. In some instances the resulting compressive strengths were below the permissible minimum value as designated by the Portland Cement Association criteria.*

The graphs (Plates 1a to 6a) were drawn to portray a design chart. Assuming that laboratory results can be duplicated in the field, the proper combination of density and cement content can be selected to provide the compressive strength desired. The compressive strength to be used as the criteria can be selected from the Portland Cement Association's tabulation of minimum acceptable compressive strength as based on a grain-size distribution curve.

The density-strength curve for the Reaume sand at seven percent cement (Plate 5), did not appear to agree with the curves at nine and eleven percent cement. This was in all probability due to a difference in the gradation of the sand. The sand used to establish the density-strength relationship at seven percent was taken from a different location in the borrow pit, than was the sand which was used to establish the other two curves. In all other instances the gradation of the soil used to establish the three curves, was the same.

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* Fig. 38 and Fig. 43
Short cut Test Procedure for Sandy soils
Appendix 1

EFFECT OF ELAPSED TIME BETWEEN MIXING AND COMPACTION ON COMPRESSIVE STRENGTH AND DENSITY

To determine the effect of elapsed time between mixing and compaction, on compressive strength, a batch of soil-cement was mixed and specimens were formed in groups of three after elapsed time intervals of 0, 0.5, 1.0, 1.5 and 2.0 hours. A silty sand (Ray Long Pit) and eight percent cement were used to form the mixture. The materials were mixed at optimum moisture content. The specimens were formed in Proctor molds and the compactive effort was varied so as to maintain a constant density. The specimens were allowed to moist cure for seven days after which their compressive strengths were determined.

The results of the test are summarized in Table 4.

The compactive effort required to maintain constant density was plotted against elapsed time. See Plate 7.

The effect of elapsed time on the density and the strength of soil-cement was investigated by molding compressive strength specimens in groups of three, at elapsed time intervals of 0, 1, 2, 3, and 4 hours. A constant compactive effort (Standard Proctor) was used. The average densities and strengths were plotted against elapsed time. Plate 8.

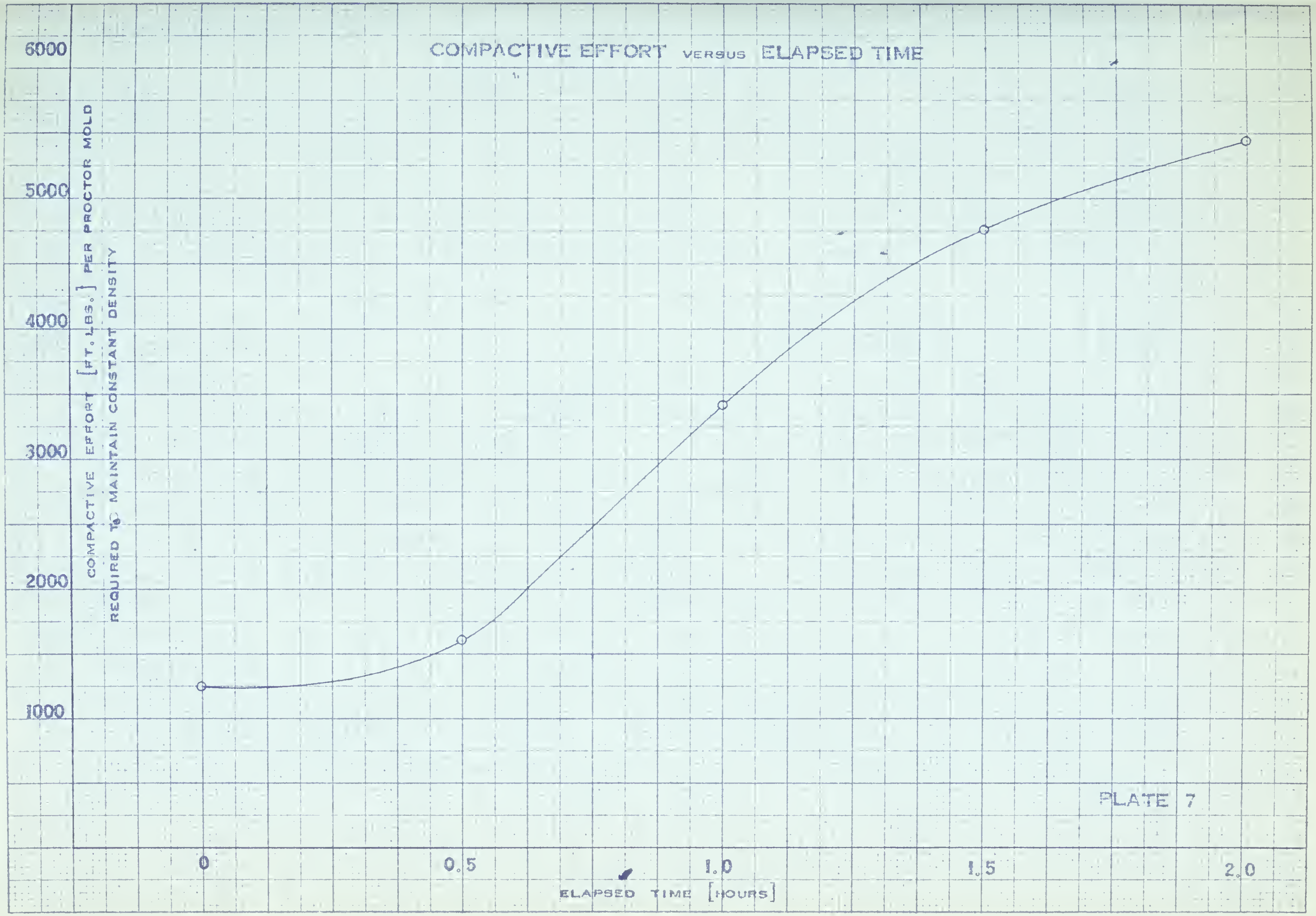

COMPACTIVE EFFORT versus ELAPSED TIME
6000
5000
4000
3000
2000
1000
COMPACTIVE EFFORT [FT. LBS.] PER PROCTOR MOLD
REQUIRED TO MAINTAIN CONSTANT DENSITY
0
0.5
1.0
1.5
2.0
ELAPSED TIME [HOURS]

PLATE 7

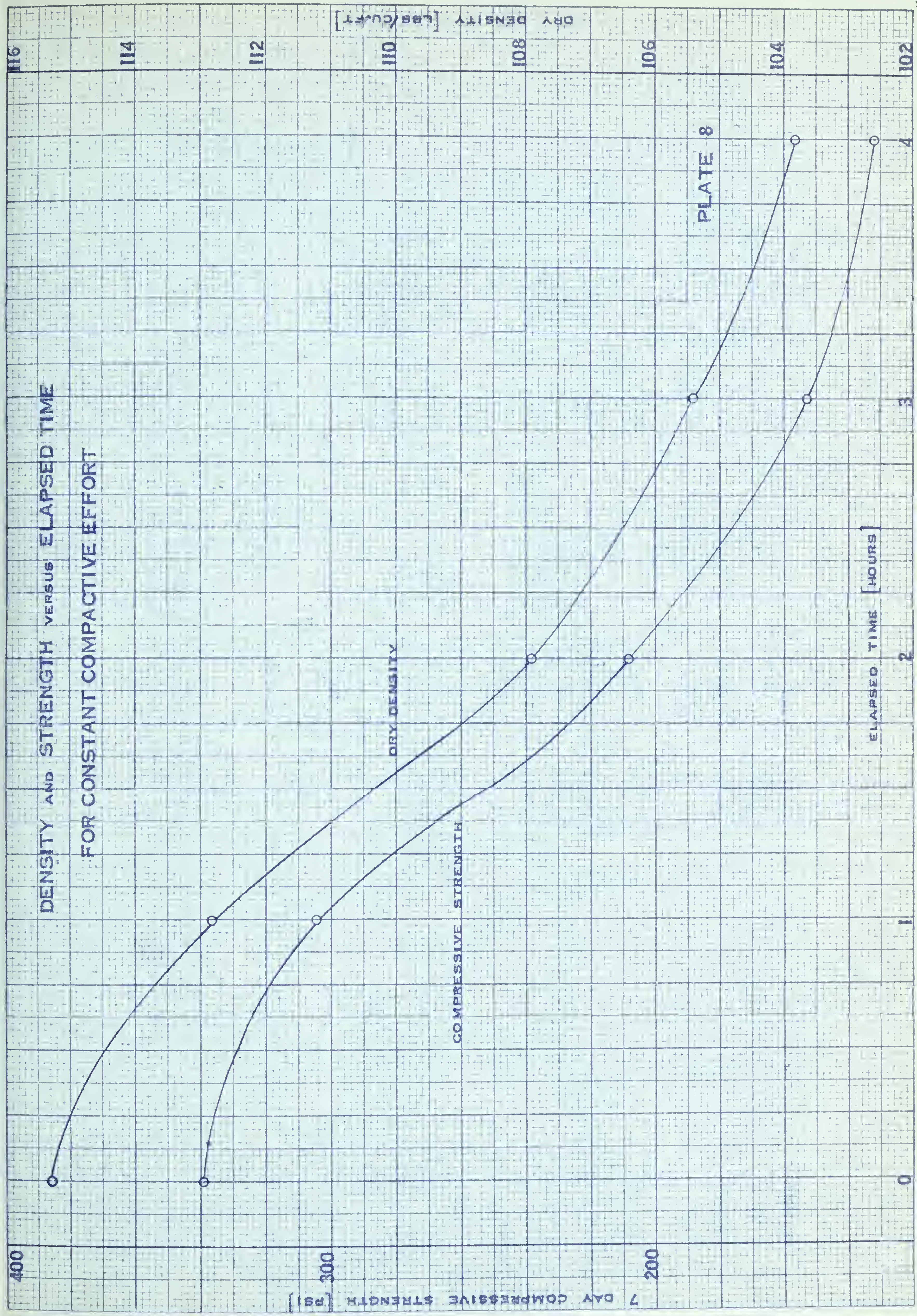

DENSITY AND STRENGTH VERSUS ELAPSED TIME
FOR CONSTANT COMPACTIVE EFFORT
PLATE 8
DRY DENSITY
COMPRESSIVE STRENGTH
DRY DENSITY [LBS/CU.FT]
116
114
112
110
108
106
104
102
7 DAY COMPRESSIVE STRENGTH [PSI]
400
300
200
ELAPSED TIME [HOURS]
0
1
2
3
4

TABLE 4

EFFECTS OF ELAPSED TIME BETWEEN MIXING AND COMPACTION ON THE COMPRESSIVE STRENGTH AND THE COMPACTIVE EFFORT

Specimen No.	Elapsed Time(hrs)	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Density	Average Strength	Average Compactive Effort
T-RL 1	0	117.6	420			
T-RL 2	0	116.8	396	117.3	428	Standard Proctor
T-RL 3	0	117.6	448			
T-RL 4	0.5	113.3	352			Std. Proct. hammer
T-RL 5	0.5	114.7	390	* 117.3	* 408	3 layers
T-RL 6	0.5	117.3	408			* 35 blows per layer
T-RL 7	1.0	118.0	410			Mod. AASHO hammer
T-RL 8	1.0	117.2	436	117.5	408	3 layers
T-RL 9	1.0	117.2	378			20 blows per layer
T-RL 10	1.5	118.7	430			Mod. AASHO hammer
T-RL 11	1.5	117.0	402	117.8	422	3 layers
T-RL 12	1.5	117.6	433			25 blows per layer
T-RL 13	2.0	117.7	406			Mod. AASHO hammer
T-RL 14	2.0	117.2	---	117.6	406	3 layers
T-RL 15	2.0	117.6	405			30 blows per layer

* Values corresponding to specimen No. T-RL 6 only

The investigation of the effects of elapsed time between mixing and compaction indicated that:

1. No appreciable loss in compressive strength occurs providing the density is maintained constant.
2. The compactive effort required to maintain constant density, increases substantially with elapsed time.

The ratios of compactive effort required after elapsed time intervals of 0.5, 1.0, 1.5 and 2.0 hours, to the compactive effort required immediately after mixing, were 1.2, 2.8, 3.8, and 4.4 respectively. This illustrates the advantage of compacting soil-cement as soon after mixing as possible.

The investigation of the effects of elapsed time and a constant compactive effort, indicated a continuous decrease in density and strength with elapsed time. The loss in density corresponding to an elapsed time of two hours was 7.8 lbs/cu.ft. or approximately seven percent, This does not appear to be a very significant loss as far as density alone is concerned. However the preceding test indicated that a 440 percent increase in compactive effort would be required to bring the material back to its original maximum density. The consequence of not maintaining a constant density, is illustrated by the compressive strength curve of Plate 8. The loss in compressive strength corresponding to an elapsed time of two hours was 132 psi or 39 percent.

Thus the significance of elapsed time between mixing and compaction is:

1. The loss in compressive strength if the density is not maintained constant.
2. The increase in compactive effort required to maintain constant density.

EFFECT OF UNIFORMITY COEFFICIENT ON THE DENSITY-STRENGTH RELATIONSHIP

The effect of varying the uniformity coefficient of the sand, on the density-strength relationship of the soil-cement was investigated in the following manner.

A silty sand was sieved down into the following sizes; minus No. 200, retained on No. 200, 100, 60, 20, and 10. Gradation curves were drawn having uniformity coefficients of 3, 5, 8 and 10. The various grain sizes were recombined according to the gradation curves. Plate 9a.

To each recombined material ten percent cement (by weight) was added. Twelve compressive strength specimens from each recombined material were formed in Miniature Harvard molds. The compactive effort was varied to attain a range of densities. The seven day compressive strengths of the specimens were determined.[1] A plot of the seven day compressive strengths versus dry densities is given by Plate 9.

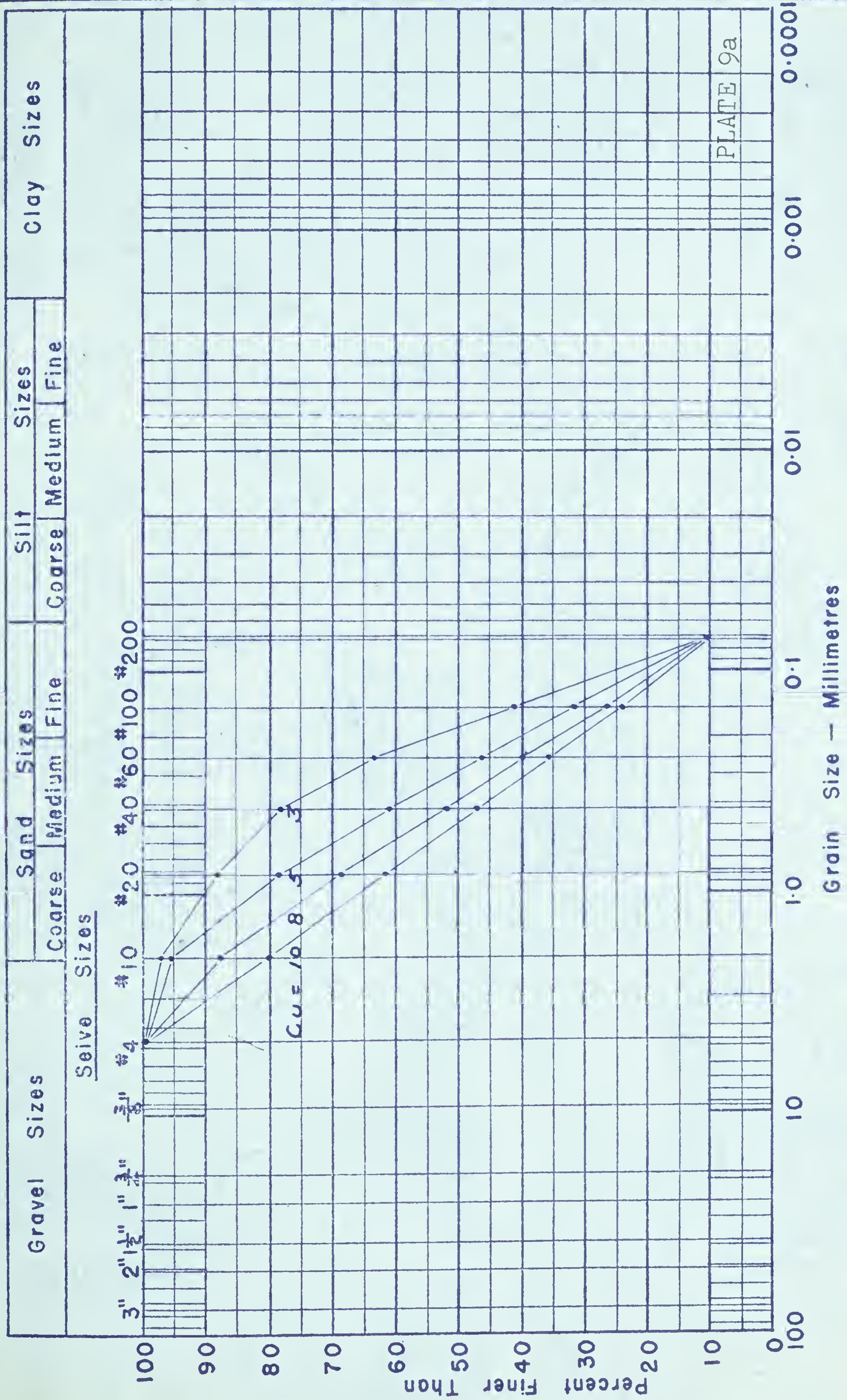
---

1. No l/d correction factor was applied since only the relative values were of concern.

UNIVERSITY of ALBERTA
DEPT. of CIVIL ENGINEERING
SOIL MECHANICS LABORATORY

GRAIN SIZE CURVE

PROJECT Soil-Cement	
SITE	
SAMPLE	
LOCATION	
HOLE	DEPTH
TECHNICIAN L.D.	DATE



Remarks: Gradations used for determining the effect of uniformity coefficient on the density-strength relationship of soil-cement.

AASHO Soil Classification: A-3

D_{10} = ____ mm.
D_{60} = ____ mm.
C_u = ____

Note: M.I.T. Grain Size Scale

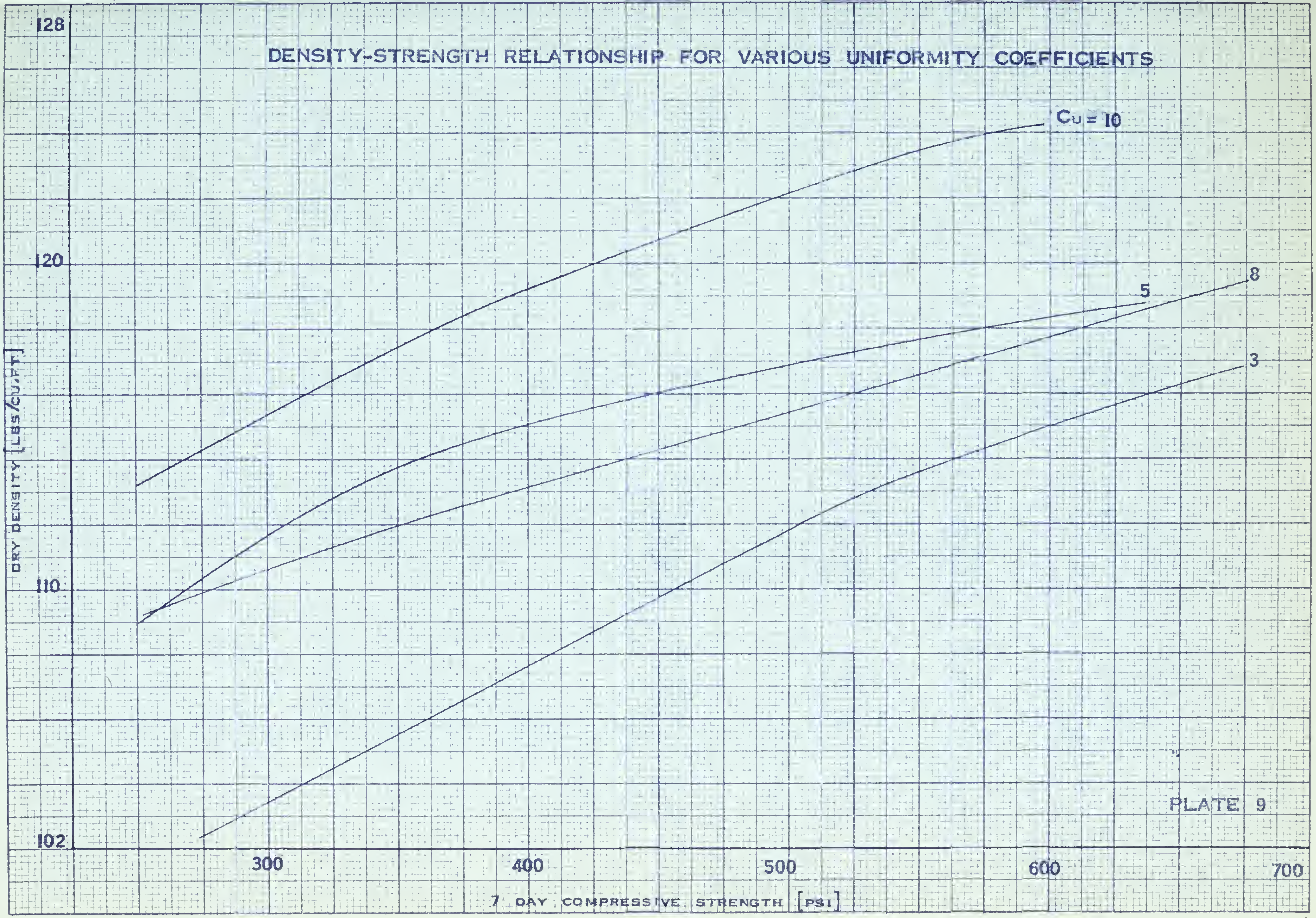

DENSITY-STRENGTH RELATIONSHIP FOR VARIOUS UNIFORMITY COEFFICIENTS
Cu = 10
5
8
3
128
120
110
102
DRY DENSITY [LBS/CU.FT]
300
400
500
600
700
7 DAY COMPRESSIVE STRENGTH [PSI]

PLATE 9

Plate 9 illustrates the effect of variations in uniformity coefficient on the density-strength relationship of soil-cement. The compressive strength corresponding to any constant density increased, as the uniformity coefficient decreased.

Example:

Density	Cu	Comp. Str.
116 lbs/cu.ft.	10	318 psi
	5	458 psi
	3	650 psi

Because of the limited extent of this investigation, the above relationship cannot be considered conclusive. More research would be required to determine any definite correlation between uniformity coefficient, and the density-strength relationship. The investigation did show that a variation in the gradation of the soil can account for a large change in the strength properties of the soil-cement, even though the soil classification remains unchanged.

If a density-strength relationship could be derived for sandy soils on the basis of uniformity coefficient, and cement content, it would provide an expedient method of design and field control, for soil-cement stabilization.

BREAKDOWN OF SANDSTONE UNDER COMPACTION

The sandstone of the Updike Lake pit existed in layers, the soundness of which varied considerably throughout the depth of the pit. Some of the sandstone layers were friable and reverted to sand readily, while others were sound enough to be crushed into aggregate. The sandstone was reduced to workable size by merely bulldozing the stratified layers onto a stockpile. The material was then passed over a set of screens to remove the oversize (plus two inch) particles. A good portion of the sound sandstone was removed in this way, and only the layers which broke up readily under the bulldozing action were used for soil-cement. Thus the possibility of a further breakdown of the sandstone during compaction existed. Since there would be no cement dispersed through any of the particles which had been broken down, this could conceivably weaken the material.

The possible extent of breakdown of the sandstone under compaction was ascertained, by comparing the grain-size distribution before compaction, to that following compaction. The material was compacted in a twelve inch diameter mold using a Proctor compacting hammer. The compactive effort was made equivalent to the Standard Proctor.

A comparison of the grain-size distribution prior to and following compaction is given in Table 5.

The crushing strength of some of the layers of sandstone was determined by cutting two inch cubes from the sandstone and determining their compressive strengths. See Table 6.

TABLE 5

BREAKDOWN OF UPDIKE LAKE SANDSTONE UNDER COMPACTION

Sieve Size	Percent Retained	
	Before Compaction	After Compaction
2	0	0
1 1/2	52	36
3/4	18	21
1/2	4	7
4	7	9
10	3	4
40	4	10
200	11.8	12.3
-200	0.2	0.7

TABLE 6

CRUSHING STRENGTH OF UPDIKE LAKE SANDSTONE

Size of specimens - 2 inch cubes

Dry Density (lbs/cu.ft)	Load Kg	Crushing Strength(psi)	Remarks
116.1	2155	1180	loaded perpendicular
119.2	2185	1200	to stratification
114.6	2080	1145	
120.3	2790	1535	loaded parallel
120.0	2840	1560	to stratification
120.3	2860	1570	
115.7	1820	1000	loaded perpendicular
112.9	1495	823	to stratification
112.9	2040	1122	
113.6	2940	1615	loaded parallel
120.8	2875	1580	to stratification
123.2	2765	1520	

Note:
The first six specimens were taken from one slab. The other six specimens were taken from a second slab. All specimens were soaked prior to breaking.

The extent of the breakdown of sandstone during laboratory compaction is illustrated by Table 5. The percent retained on the 1 1/2 inch screen decreased sixteen percent. The most significant increase in the percent retained, was on the No. 40 sieve. This indicates that some of the sandstone was reverted to sand under the force of compaction.

The extent to which this occurred during field compaction depended on several factors:

1. Type of compacting equipment.

In the laboratory investigation, the material was compacted by impact. In the field a kneading action (rubber-tire rollers) was used. The laboratory method of compaction could be expected to be more severe in this respect, than the field method.

2. Gradation of the material.

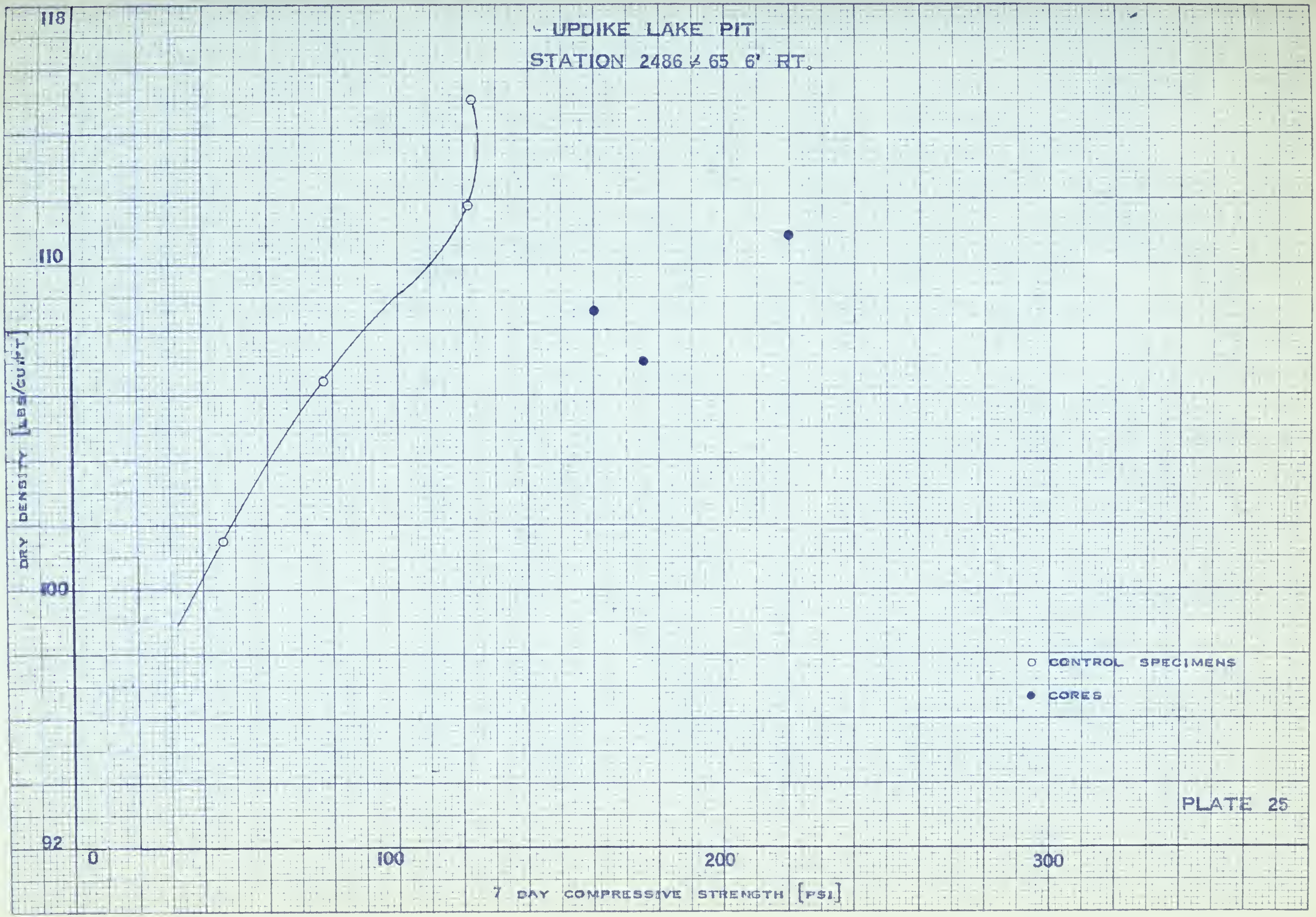
A well graded sandstone is less susceptible to breakdown under compaction than is a poorly graded sandstone.

3. The crushing strength of the sandstone versus the unit contact pressures of the compacting equipment.

The crushing strengths as determined by the compressive strength tests on the two inch cubes (Table 6), were greater than any unit contact pressure used during compaction. However, the sandstone slabs from which the cubes were cut, were not representative of all the sandstone which was used for soil-cement. The only slabs which were available for such a test were those which had withstood crushing by the bulldozing action. Thus they represented a small portion of all the sandstone used.

An example of the possible effects of a substantial breakdown of sandstone under compaction is illustrated by Plate 25. This is one of several similar density-strength curves that was obtained in the field, for the Updike Lake sandstone. The increase in strength per unit increase in density was fairly constant up to a density of approximately 109 lbs/cu.ft. From here on, the increase in strength per unit increase in density, dropped off until at 113 lbs/cu.ft. any further increase in density brought about a decrease in strength. The Standard Proctor density of the material was 115 lbs/cu.ft.

It is unlikely that this occurred to as great a degree, in the actual compaction of the material in the field. A Marshall compacting hammer was used to compact the specimens. The impact of the hammer brought about a substantial breakdown of the sandstone at relatively high densities. It is unlikely that the degree of breakdown of the sandstone was as great under the kneading action of the field compacting equipment. However, Plate 25 does illustrate the importance of minimizing the extent to which sandstone is broken down during compaction. A means of avoiding the situation depicted by Plate 25 would be to crush the sandstone. The relatively weak sandstone would revert to sand, and only the sound sandstone would remain as aggregate.


UPDIKE LAKE PIT
STATION 2486 + 65 6' RT.
118
110
100
92
DRY DENSITY [LBS/CU.FT]
0
100
200
300
7 DAY COMPRESSIVE STRENGTH [PSI]
CONTROL SPECIMENS
CORES
PLATE 25

INCREASE IN DRY DENSITY OF SOIL-CEMENT DUE TO HYDRATION

The hydration of cement brings about an increase in the dry density of soil-cement in two ways.

1. The accompanying reduction in volume.
2. The increase in the weight of the cement as it hydrates.

Since density was to be used as the basis for correlating the field strength of the soil-cement with that produced in the laboratory, the descrepancy between the densities of specimens as formed, and densities following seven days of curing, was investigated.

Two methods were used to determine the increase in dry density.

1. The increase brought about by the volume reduction plus the increase in the weight of cement.

Specimens were formed in Proctor molds and allowed to moist cure for seven days. Their densities, as molded, were computed. Following the seven day curing period, their densities were recomputed by redetermining the volumes, the wet weights and the moisture contents. The results are given in Table 7.

2. The increase in dry density of the soil-cement brought about by an increase in the weight of the cement alone.

A known weight of dry cement was mixed into a paste and allowed to hydrate for seven days. Its dry weight was then determined and the percent increase in weight was computed.

The increase in the dry density of the specimens used in the first method was computed on the basis of the increase in the weight of the cement alone. See Table 8.

TABLE 7

INCREASE IN DRY DENSITY OF SOIL-CEMENT DUE TO HYDRATION

Specimen No.	Density lbs/cu.ft. As Formed	Density lbs/cu.ft. After Hydration	Increase In Density	% Increase	Volume (cc) As Formed	Volume (cc) After Hydration
C - R1	112.6	113.7	1.1	1.0	938	938
C - R2	109.8	110.9	1.1	1.0	938	937
C - R3	109.8	111.1	1.2	1.2	938	930
C - R4	105.5	107.8	1.2	1.1	938	935
C - R5	107.1	108.2	1.1	1.0	938	932
C - R6	101.0	102.3	1.3	1.3	938	935
C - R7	100.0	100.9	0.9	0.9	938	938

Average increase in density = 1.1%

TABLE 8

INCREASE IN DRY DENSITY OF SOIL-CEMENT DUE TO INCREASE IN WEIGHT OF HYDRATED CEMENT

Sample No.	Weight of Dry Cement (gms) Before Hydration	After Hydration	Increase In Weight (gms)	Percent Increase
1	182.47	204.80	22.33	12.2
2	162.25	182.81	20.56	12.7
3	155.48	174.31	18.83	12.1

Average increase in weight of cement after 7 days of hydration = 12.3%

Increase in dry density of soil-cement used in preceding investigation

$$\text{Percent Increase} = \frac{\text{Unit weight of soil-cement (as formed)} + \text{Increase in weight of cement}}{\text{Unit weight of soil-cement (as formed)}}$$

Average unit weight of soil-cement = 107.2 lbs/cu.ft.
Cement content = 11%

$$\therefore \text{Percent increase} = \frac{107.2 + (.11 \times 107.2 \times .123)}{107.2} = \underline{1.0\%}$$

The percent increase in the dry density of the soil-cement due to a seven day hydration period was;

1. 1.1% as determined by independent computations of densities prior to, and after the hydration period.
2. 1.0% as based on the increase in the weight of hydrated cement.

On the basis of the above values, it can be concluded that the increase in dry density of soil-cement that accompanys hydration, is primarily the result of the increased weight of the hydrated cement. Because the reduction in volume brought about by hydration was small, the resulting increase in dry density was almost negligible.

Assuming the increase in dry density due to a reduction in volume is negligible, the percent increase in dry density of any soil-cement mixture can be computed on the basis of; the unit weight of the soil, the cement content, and the percent increase in the weight of cement as it hydrates. This increase would have to be taken into account in any laboratory correlation, in which the density was determined at any time other than when the soil-cement specimens were molded.

The increase was not used in correlating field results with laboratory values, because the accuracy with which the densities were determined in the field, did not warrant a one percent correction.

HEALING POWER OF SOIL-CEMENT

In order to assess the ability of soil-cement to regain compressive strength after being fractured, soil-cement specimens which had been used to determine the seven day compressive strengths were allowed to moist cure for an additional period of time. Their compressive strengths were then redetermined and compared with the seven day compressive strengths. The results of such are given in Table 9.

In determining the compressive strengths, the load which caused initial failure of the specimens was used in both instances.

TABLE 9

STRENGTH OF FRACTURED SOIL-CEMENT SPECIMENS FOLLOWING ADDITIONAL HYDRATION

Specimen No.	7 day compressive Strength(psi)	Fractured Specimens Age(days)	Fractured Specimens Strength(psi)	Increase In Strength	% Increase
H-R 1	378	14	418	40	11
H-R 2	387	22	495	108	28
H-R 3	433	22	620	187	43
H-R 4	437	22	628	191	43
H-R 5	308	49	432	124	40
H-R 6	300	49	442	142	47
H-R 7	394	62	610	216	55
H-R 8	435	62	745	310	71
H-R 9	505	62	845	340	68
H-R 10	502	62	863	361	72
H-R 11	273	62	500	227	83
H-R 12	247	62	415	168	68
H-R 13	335	62	665	330	98
H-R 14	343	62	673	330	96

Soil-cement specimens which were used to determine the seven day compressive strength and then allowed to moist cure for an additional period of time, showed an increase in compressive strength when retested. The increase in compressive strength ranged from eleven percent in seven additional days of moist curing, to 98 percent in 55 additional days. The practical significance of this is somewhat limited since any fractures induced in the soil-cement pavement by premature loading, would only heal to the same extent, in the absence of further loading. The rate at which it regained strength would depend upon the age at which it was fractured. However, the results indicate that if a soil-cement pavement fails to a minor degree, under premature loading, the situation may be corrected by discontinuing the use of the pavement until the soil-cement has had sufficient time to regain strength.

CONCLUSIONS OF LABORATORY INVESTIGATION

On the basis of the soils tested, the following conclusions were drawn regarding the engineering properties of soil-cement:

1. The relationship between density and strength of soil-cement is such, that a small decrease in density, results in an appreciable loss in compressive strength. The relationship was linear for most soils, and a decrease in density from 100 to 95 percent Standard Proctor, accounted for a loss of 25 to 30 percent in the compressive strength.
2. The following are the effects of elapsed time between mixing and final compaction, on the properties of the soil-cement.

(i) There is no appreciable loss in compressive strength within an elapsed time of two hours providing the density is kept constant.

(ii) The compactive effort required to maintain constant density, increases substantially with elapsed time. The compactive effort required after elapsed time intervals of 0.5, 1.0, 1.5 and 2.0 hours was respectively, 1.3, 2.8, 3.8 and 4.4 times as great as the compactive effort required immediately after mixing.

(iii) If the compactive effort is kept constant there is a decrease in density with elapsed time, the consequence of which is a substantial loss in compressive strength. An elapsed time of two hours accounted for a seven percent loss in density. The corresponding

loss in compressive strength was 39 percent.

3. The density-strength properties of any one soil group cannot be expressed by a single density-strength curve. A variation in the grain-size distribution, without changing the soil-classification, alters the density-strength relationship. The investigation showed that the strength increased by 100 percent when the uniformity coefficient of an A-3 soil was reduced from ten to three, all other factors being constant. The purpose of this investigation was to determine the extent to which variations in the gradation of a soil group altered the density-strength relationship. A more comprehensive investigation would be required to correlate the uniformity coefficient with the density-strength relationship.
4. Soil-cement containing sandstone is weakened, if the sandstone is broken down under compaction.
5. Hydration of cement brings about an increase in the dry density of soil-cement. The increase is almost exclusively due to the increase in the weight of cement, as it hydrates. The increase brought about by the reduction in volume that accompanies hydration, is almost negligible. The weight of cement increased by 12.3 percent in a hydration period of seven days. The increase in dry density of soil-cement can be computed, if in addition to the above, the unit weight of the soil and the cement content is known.

6. Fractured soil-cement will regain strength in the absence of further loading. The strength which it attains after fracturing, depends upon the age at which it was fractured. Specimens which had been fractured at seven days and then allowed to moist cure for an additional seven days showed an eleven percent increase in strength. In 55 additional days, the percent increase in strength was approximately 95 percent.

CHAPTER 5

CORRELATION OF FIELD AND LABORATORY PROPERTIES OF SOIL-CEMENT

The engineering properties of the soil-cement base course produced in the field were compared with the properties determined in the laboratory investigation, on the basis of the following:

1. Seven day compressive strengths.
2. Ability to withstand exposure to the elements as determined by freeze-thaw tests.
3. Mixing uniformity.
4. Variations in gradation

CORRELATION OF COMPRESSIVE STRENGTHS

Soil-cement cores were taken in the field by means of a portable coring apparatus mounted on a truck. The internal diameter of the core barrel measured four inches, and the cores were taken the full six inch depth of the base course. The cores were trimmed, usually to a height of 4.6 inches, thus making them equivalent to a Proctor mold specimen. They were then moist-cured for the remainder of the seven day period,[1] and their compressive strengths were determined. The dry density of each core was computed, by determining the volume, the wet weight and the moisture content. The strengths were compared

---

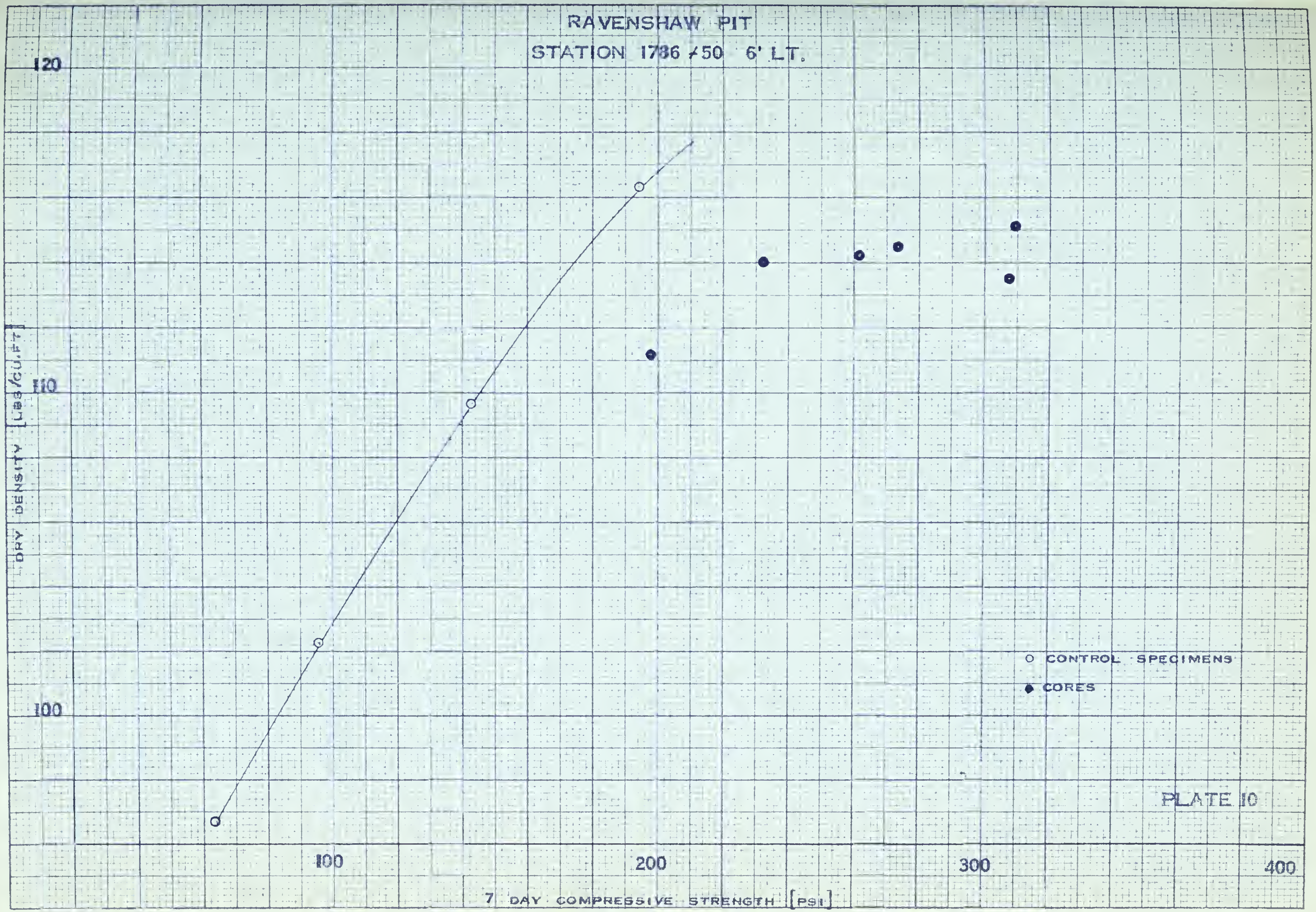
1. Coring was done three or four days after the soil-cement mixture had been placed, to provide sufficient time for shipping some of the cores that were to undergo freeze-thaw tests, to the highway laboratory.

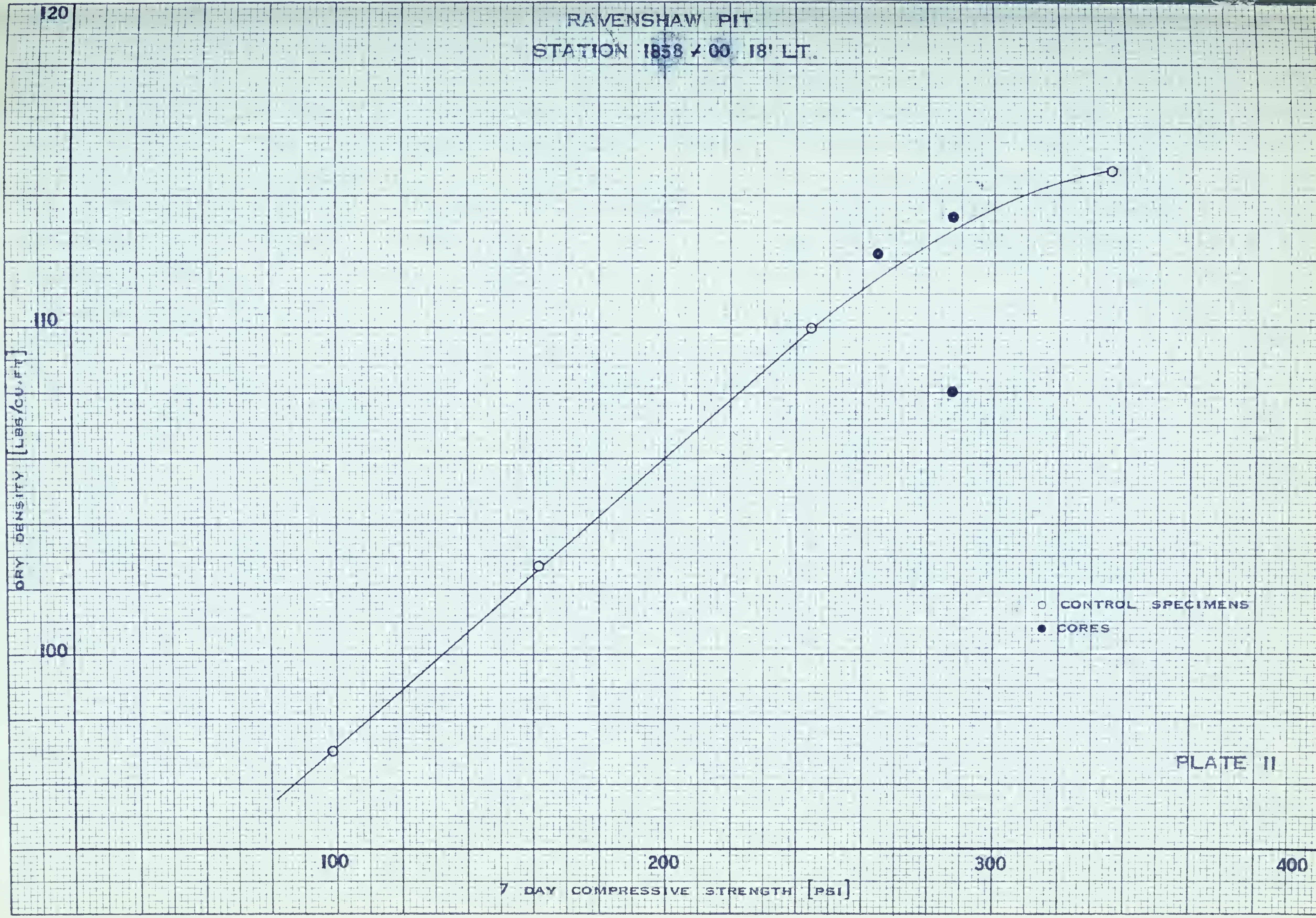
with the respective laboratory strengths on the basis of density and estimated cement content. This was found unsatisfactory because of such variables as cement content and gradation. To properly assess the quality of the base-course, additional control strength values were established in the field. Density-strength relationships were determined using plant-mix material. The procedure used was identical to that outlined in Chapter 4. The location from which the material was taken for the density-strength specimens was noted, and later cores were taken from this location. The seven day compressive strengths of the cores were determined and were compared to the "control" strengths at the respective densities. All such density-strength curves and the corresponding core values were plotted on one graph to illustrate the control, and the actual, range in densities and strengths. Any cores taken from areas other than those represented by the density-strength curves were also plotted on this graph. Other information included on the graph was:

1. The density-strength relationship as determined in the laboratory investigation.
2. 100 percent and 95 percent Standard Proctor (SP) as determined in the laboratory investigation.
3. Minimum permissible compressive strength as set out by the Portland Cement Association Criteria (Figs. 38 and 43 Short-cut Test Procedure For Sandy Soils Appendix).
4. Cement contents corresponding to the density-strength curves.

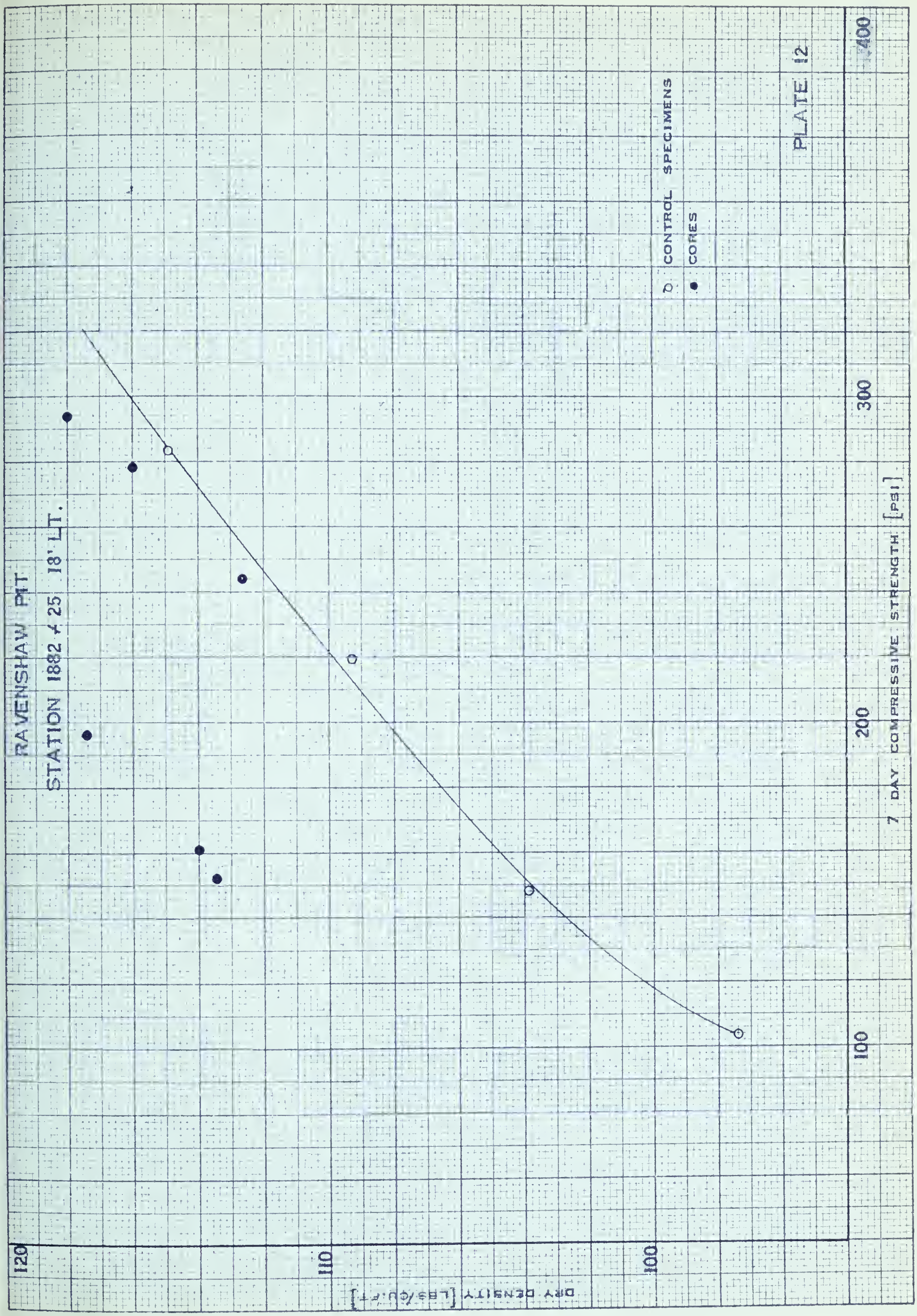
The soil-cement corresponding to the Ravenshaw, Reaume, and Updike Lake pits was evaluated in this manner. Plates 10 to 30 illustrate the comparison of the core strengths with the control strengths at various locations of the project. Plates 31, 32, and 33 are summaries of all the strength data obtained for each pit material.

No density-strength relationships were established in the field for the Elhardt soil-cement. The only control values of strength were those obtained by molding seven day compressive strength specimens at Standard Proctor compactive effort. The soil-cement used for forming the specimens was taken from the spreader and the location was noted. Cores were later taken from the same areas and their seven day compressive strengths were compared with the control strengths. See Table 10.


RAVENSHAW PIT
STATION 1786 +50 6' LT.
120
110
100
DRY DENSITY [LBS/CU.FT]
100
200
300
400
7 DAY COMPRESSIVE STRENGTH [PSI]
o CONTROL SPECIMENS
• CORES
PLATE 10



RAVENSHAW PIT
STATION 1858 + 00 18' LT.
120
110
100
DRY DENSITY [LBS/CU.FT]
100
200
300
400
7 DAY COMPRESSIVE STRENGTH [PSI]
CONTROL SPECIMENS
CORES
PLATE II


RAVENSHAW PIT
STATION 1882 + 25 18' LT.
CONTROL SPECIMENS
CORES
PLATE 12
100
200
300
400
7 DAY COMPRESSIVE STRENGTH [PSI]
120
110
100
DRY DENSITY [LBS/CU.FT]

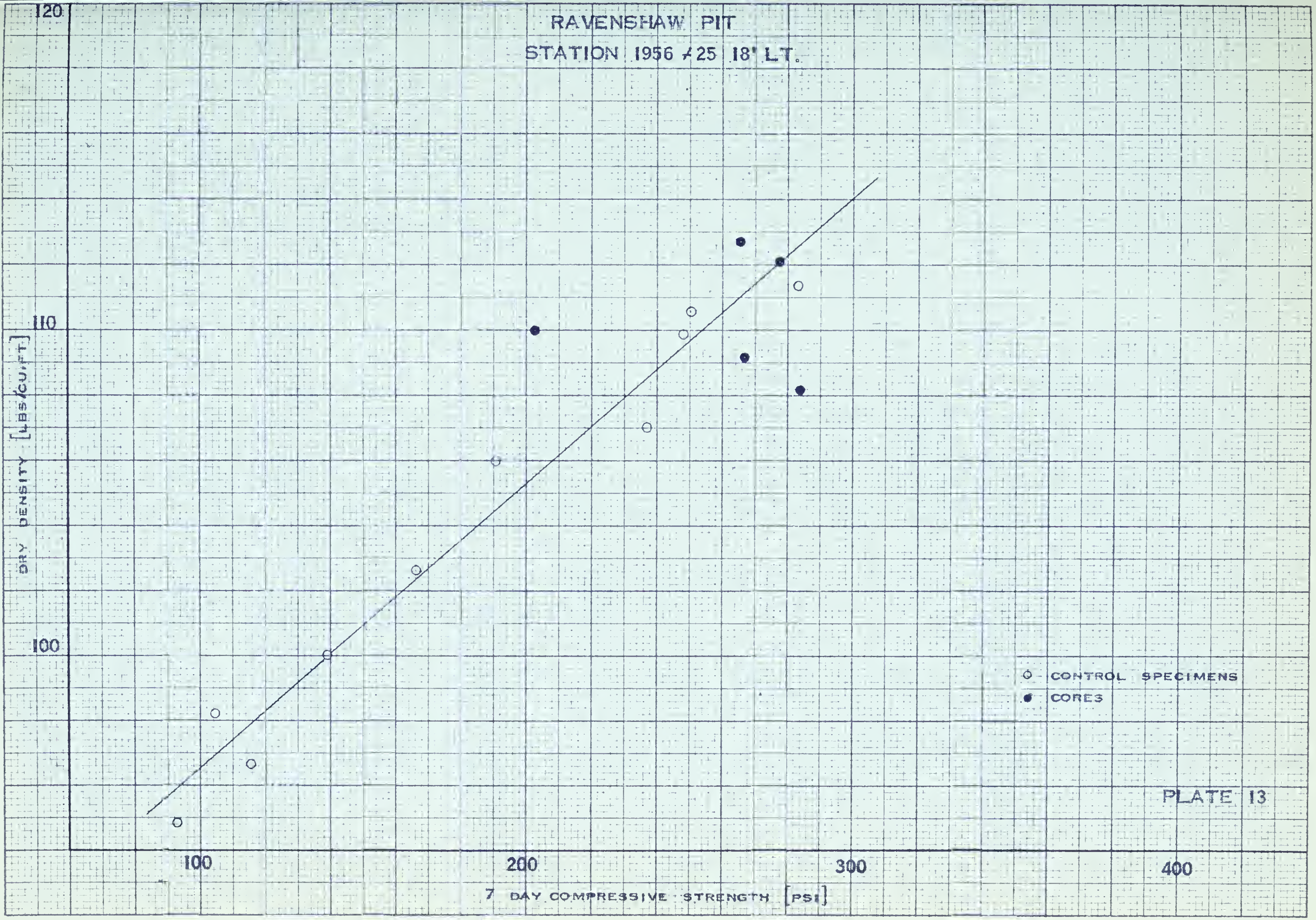
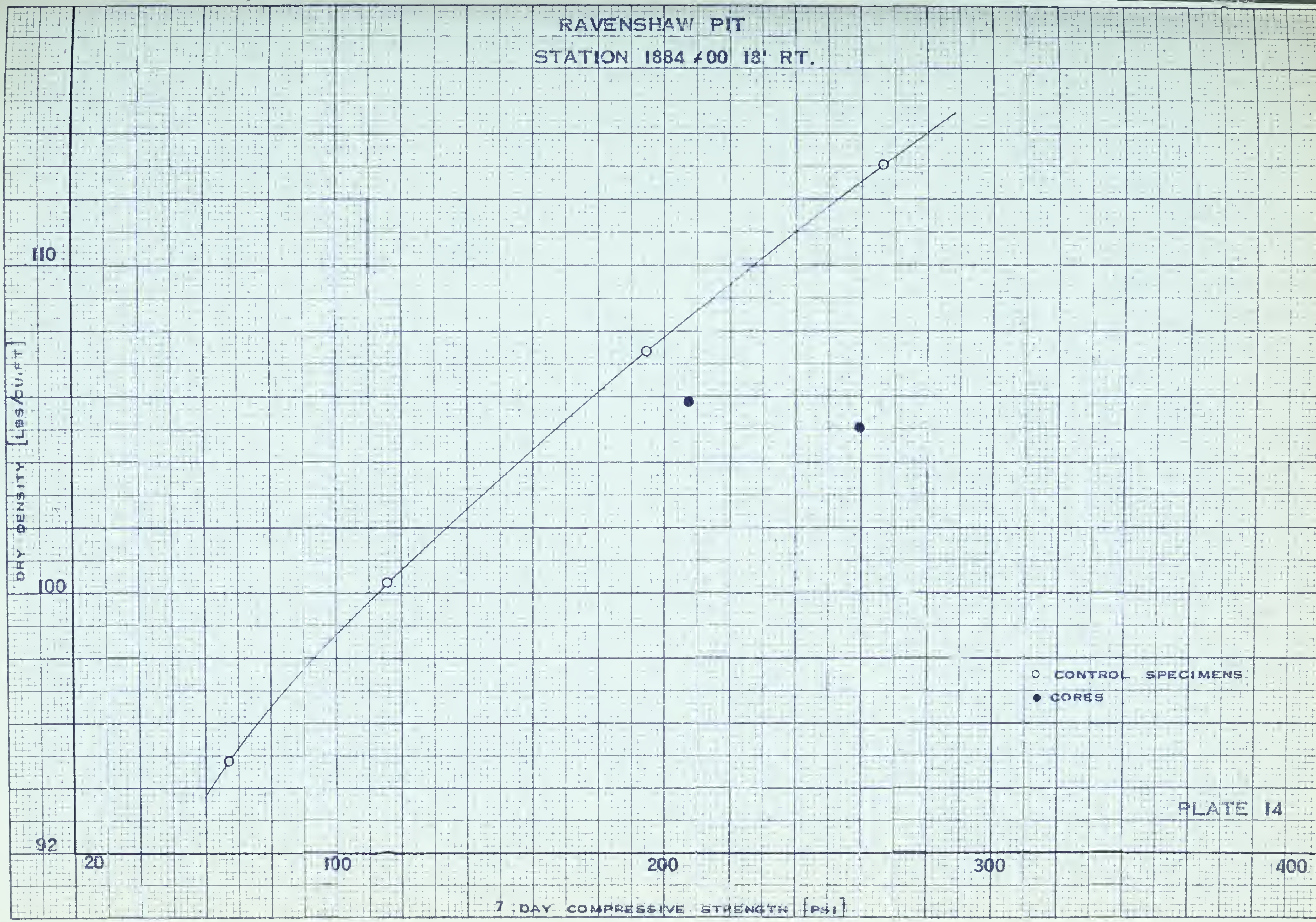

RAVENSHAW PIT
STATION 1956 + 25 18' LT.
120
110
100
DRY DENSITY [LBS/CU.FT]
100
200
300
400
7 DAY COMPRESSIVE STRENGTH [PSI]
CONTROL SPECIMENS
CORES

PLATE 13


RAVENSHAW PIT
STATION 1884 ≠00 18' RT.
110
100
92
DRY DENSITY [LBS/CU.FT]
20
100
200
300
400
7 DAY COMPRESSIVE STRENGTH [PSI]
○ CONTROL SPECIMENS
● CORES
PLATE 14

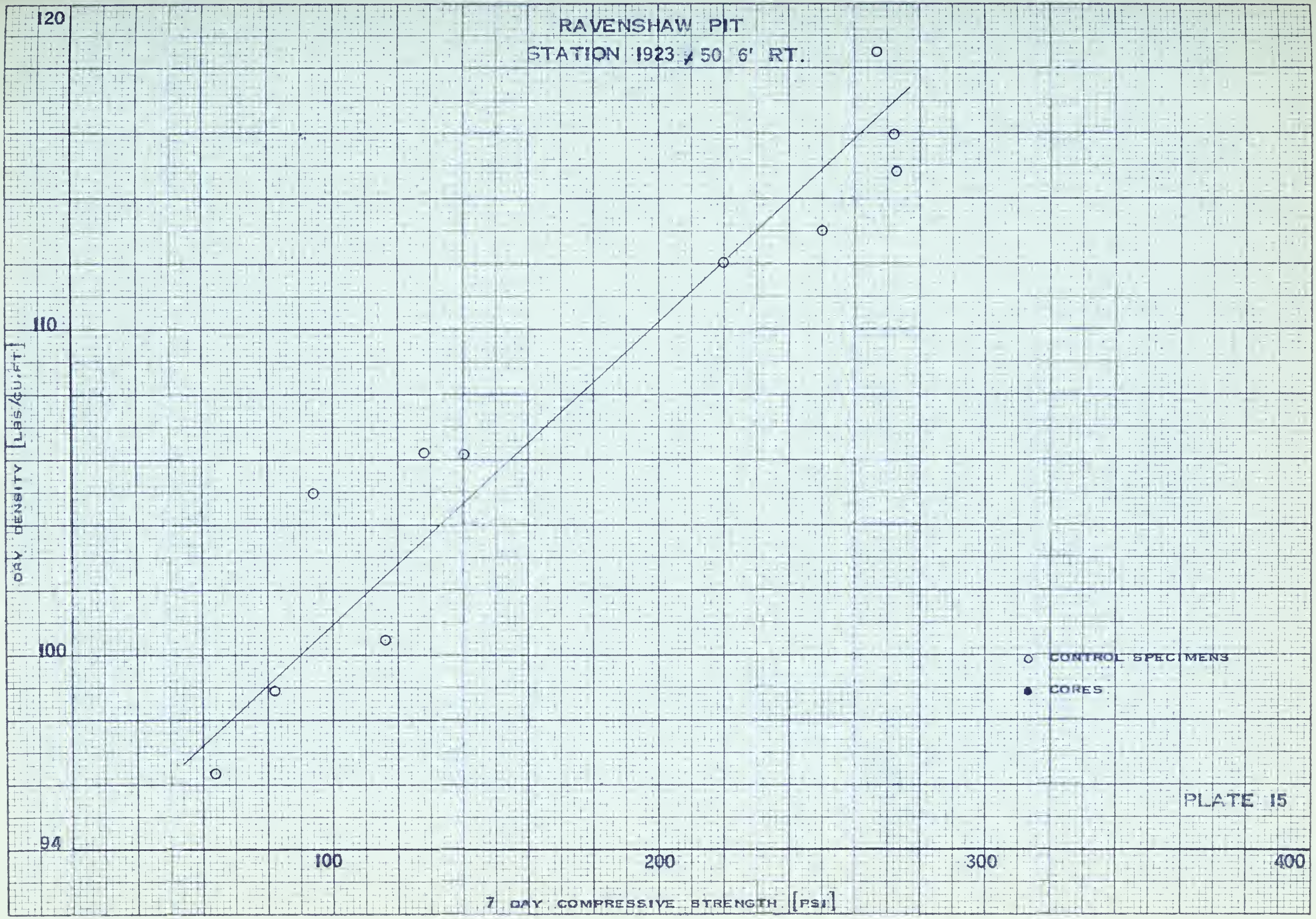
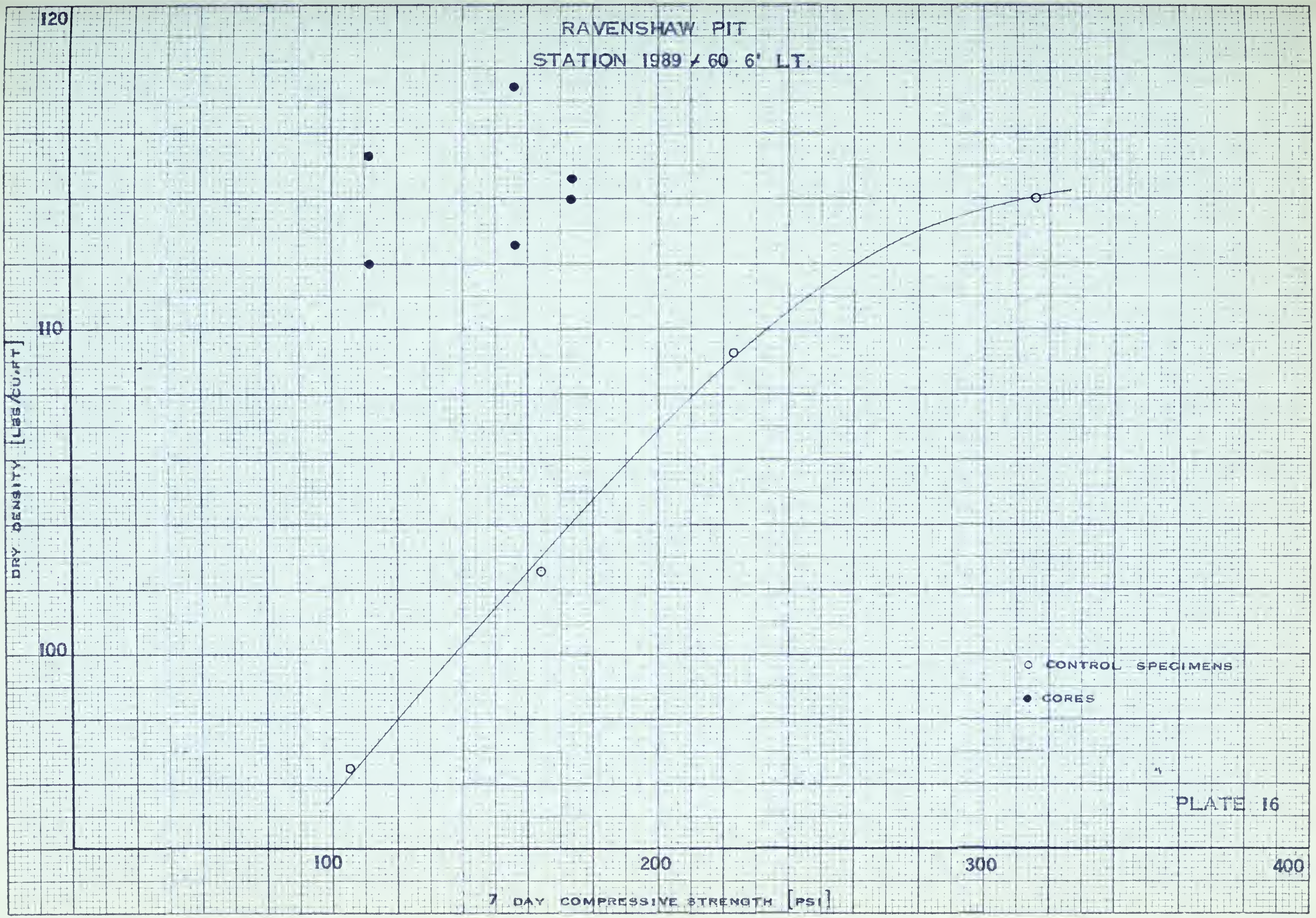
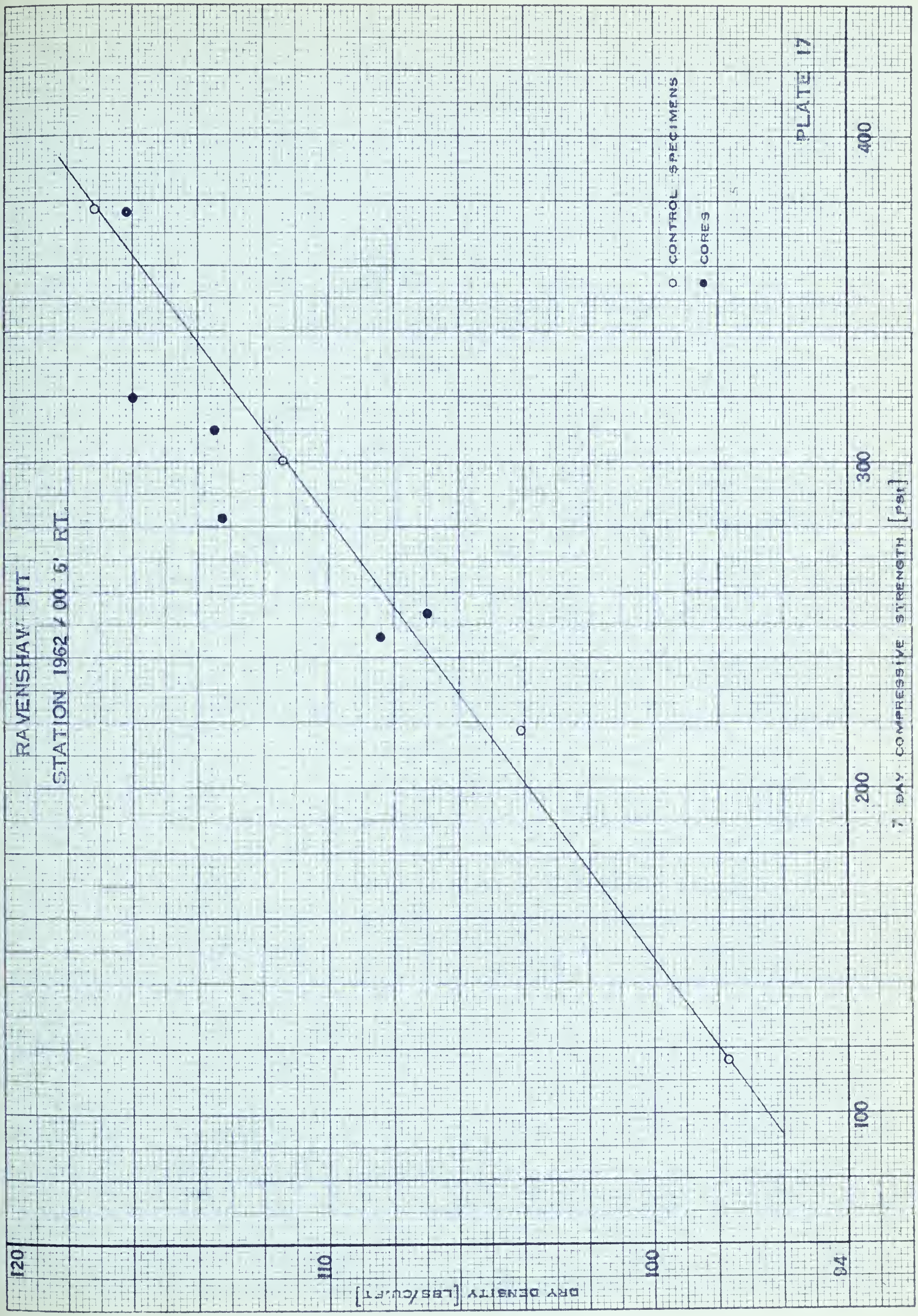
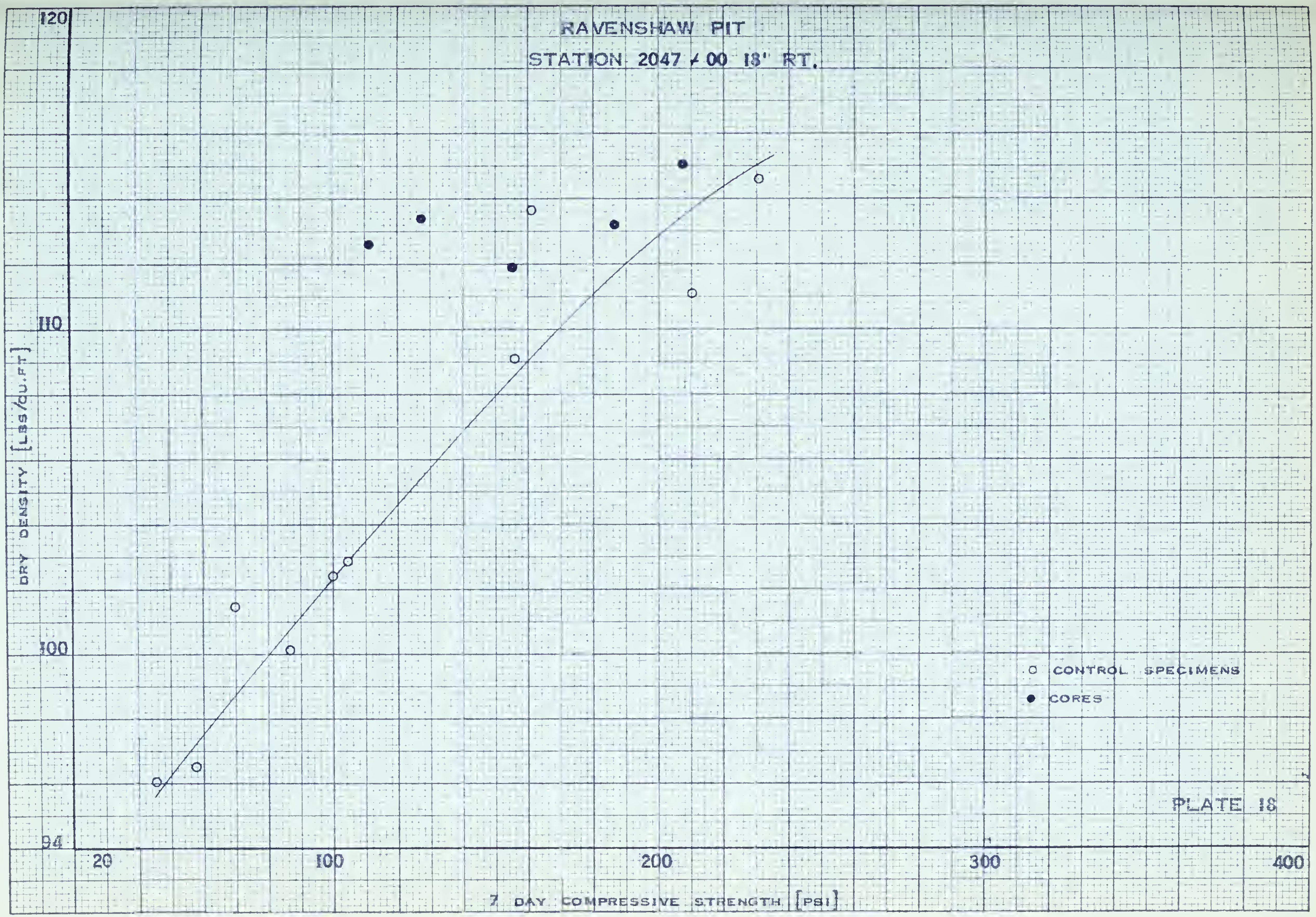
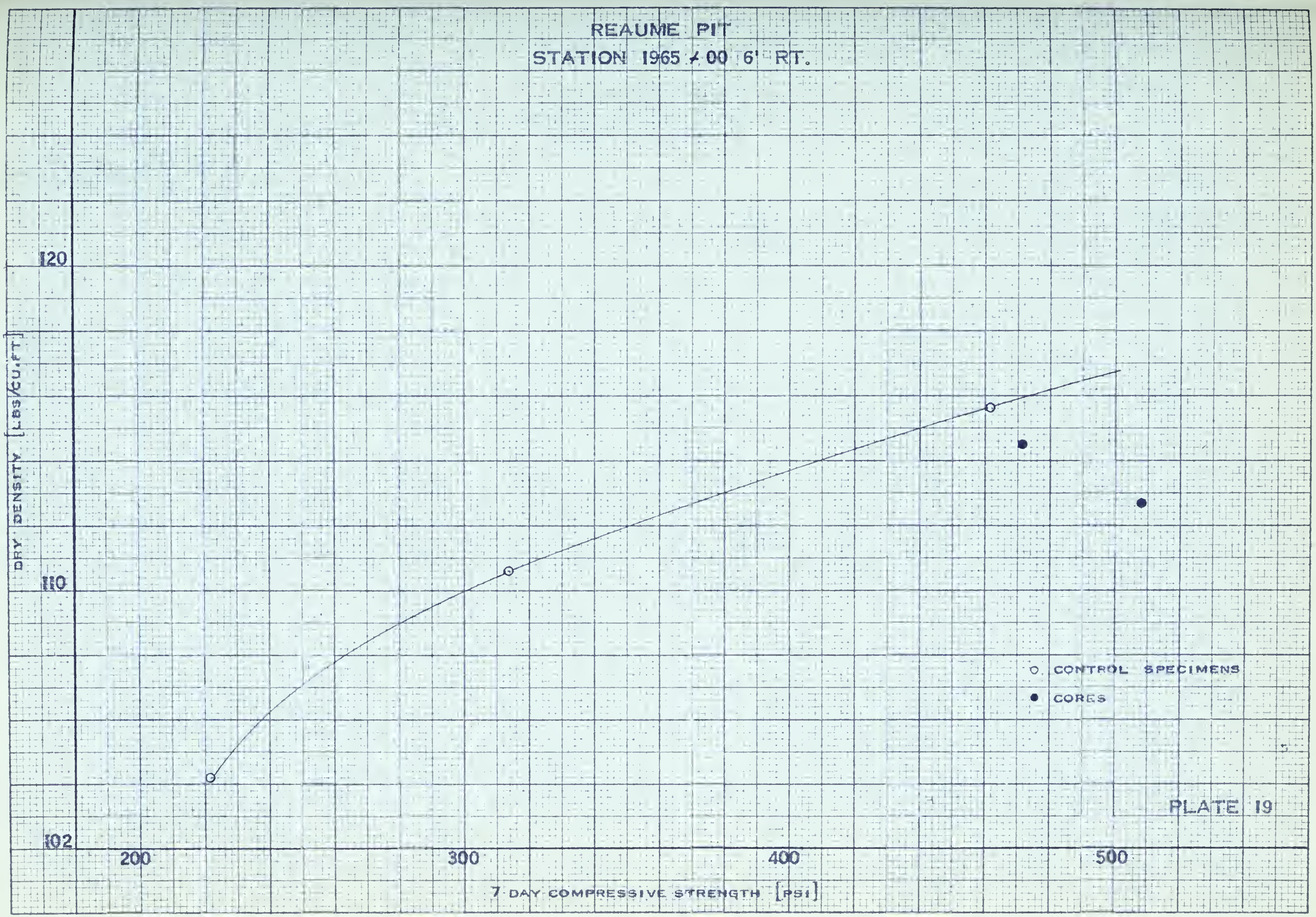

RAVENSHAW PIT
STATION 1923 + 50 6' RT.
120
110
100
94
DRY DENSITY [LBS/CU.FT]
100
200
300
400
7 DAY COMPRESSIVE STRENGTH [PSI]
CONTROL SPECIMENS
CORES

PLATE 15


RAVENSHAW PIT
STATION 1989 + 60 6' LT.
120
110
100
DRY DENSITY [LBS/CU.FT]
100
200
300
400
7 DAY COMPRESSIVE STRENGTH [PSI]
○ CONTROL SPECIMENS
● CORES
PLATE 16

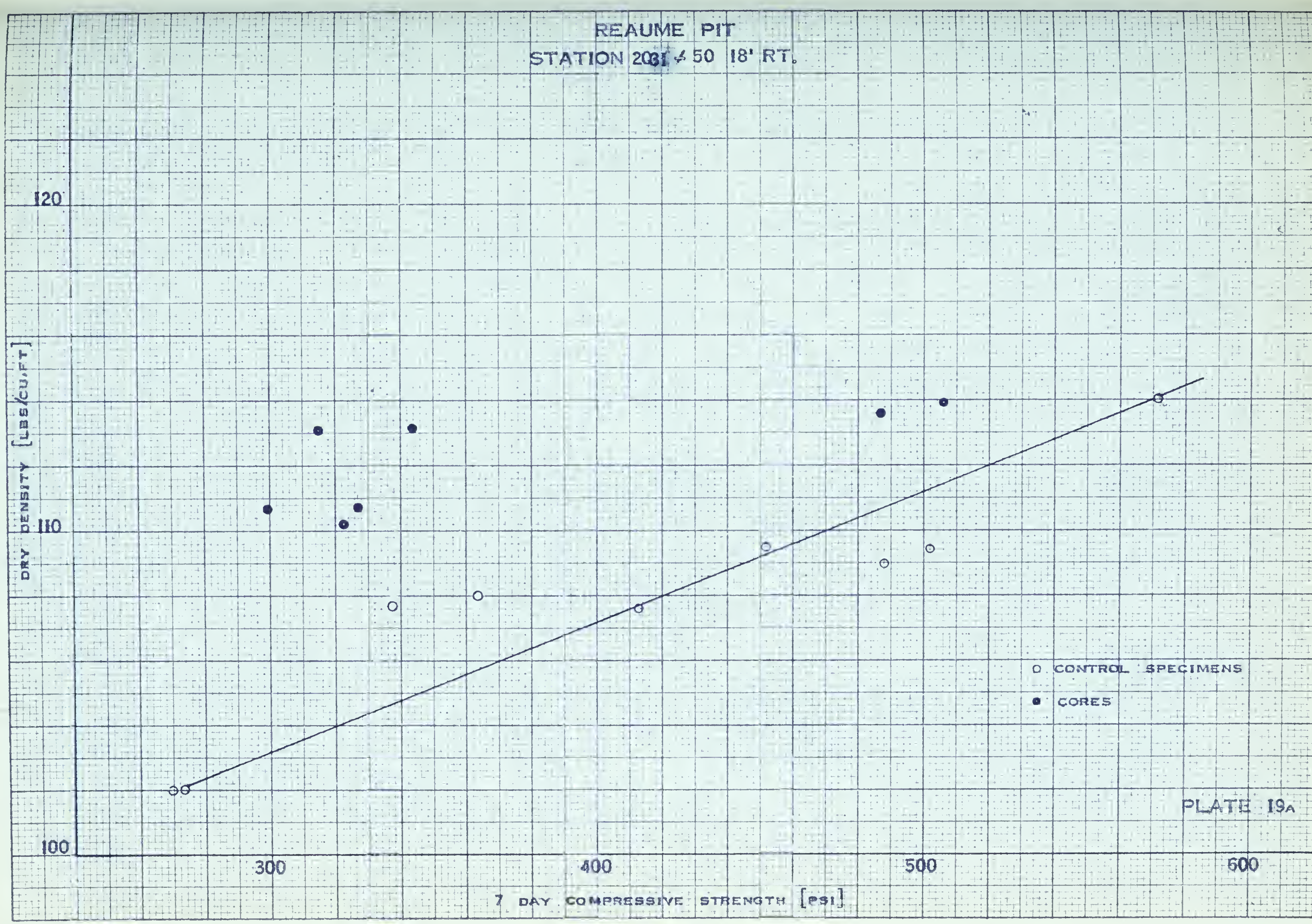

RAVENSHAW PIT
STATION 1962 ≠ 00 6' RT.
o CONTROL SPECIMENS
• CORES
PLATE 17
120
110
100
94
DRY DENSITY [LBS/CU.FT]
100
200
300
400
7 DAY COMPRESSIVE STRENGTH [PSI]


RAVENSHAW PIT
STATION 2047 + 00 18' RT.
120
110
100
94
DRY DENSITY [LBS/CU.FT]
20
100
200
300
400
7 DAY COMPRESSIVE STRENGTH [PSI]
CONTROL SPECIMENS
CORES
PLATE 18



REAUME PIT
STATION 1965 + 00 6' RT.
120
110
102
DRY DENSITY [LBS/CU.FT]
200
300
400
500
7 DAY COMPRESSIVE STRENGTH [PSI]
○ CONTROL SPECIMENS
● CORES

PLATE 19


REAUME PIT
STATION 2031 + 50 18' RT.
120
110
100
DRY DENSITY [LBS/CU.FT]
300
400
500
600
7 DAY COMPRESSIVE STRENGTH [PSI]
○ CONTROL SPECIMENS
● CORES
PLATE 19A

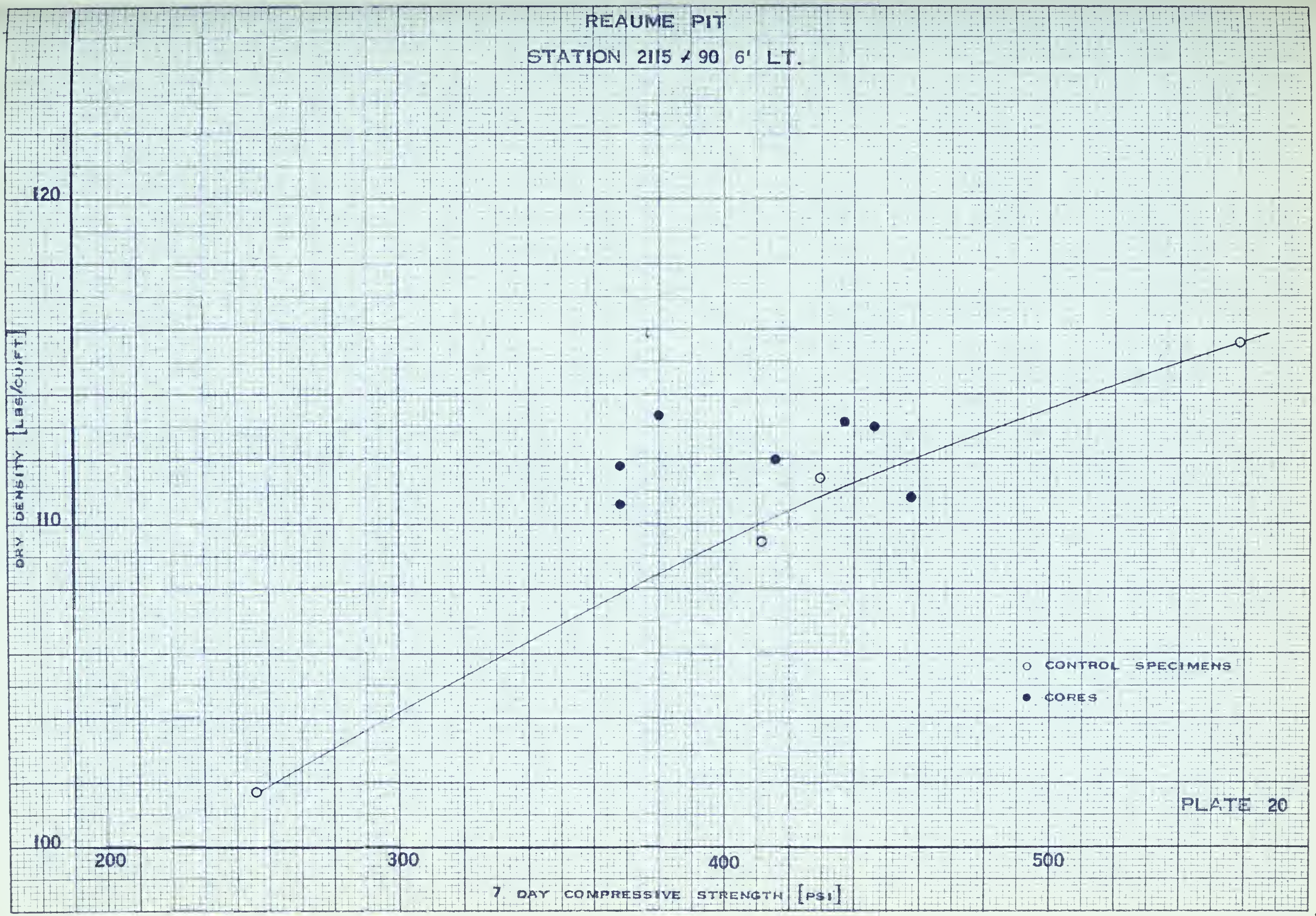
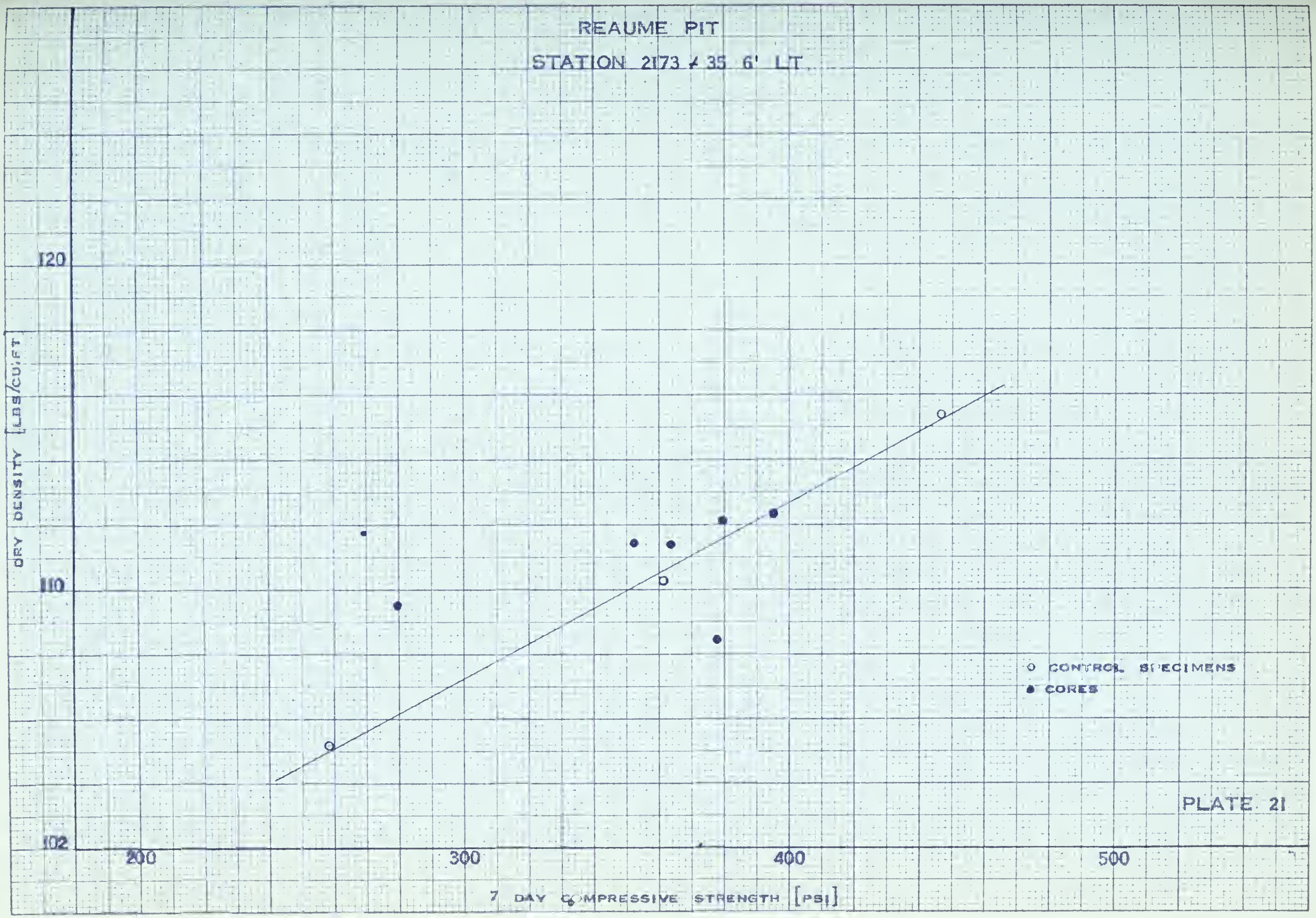
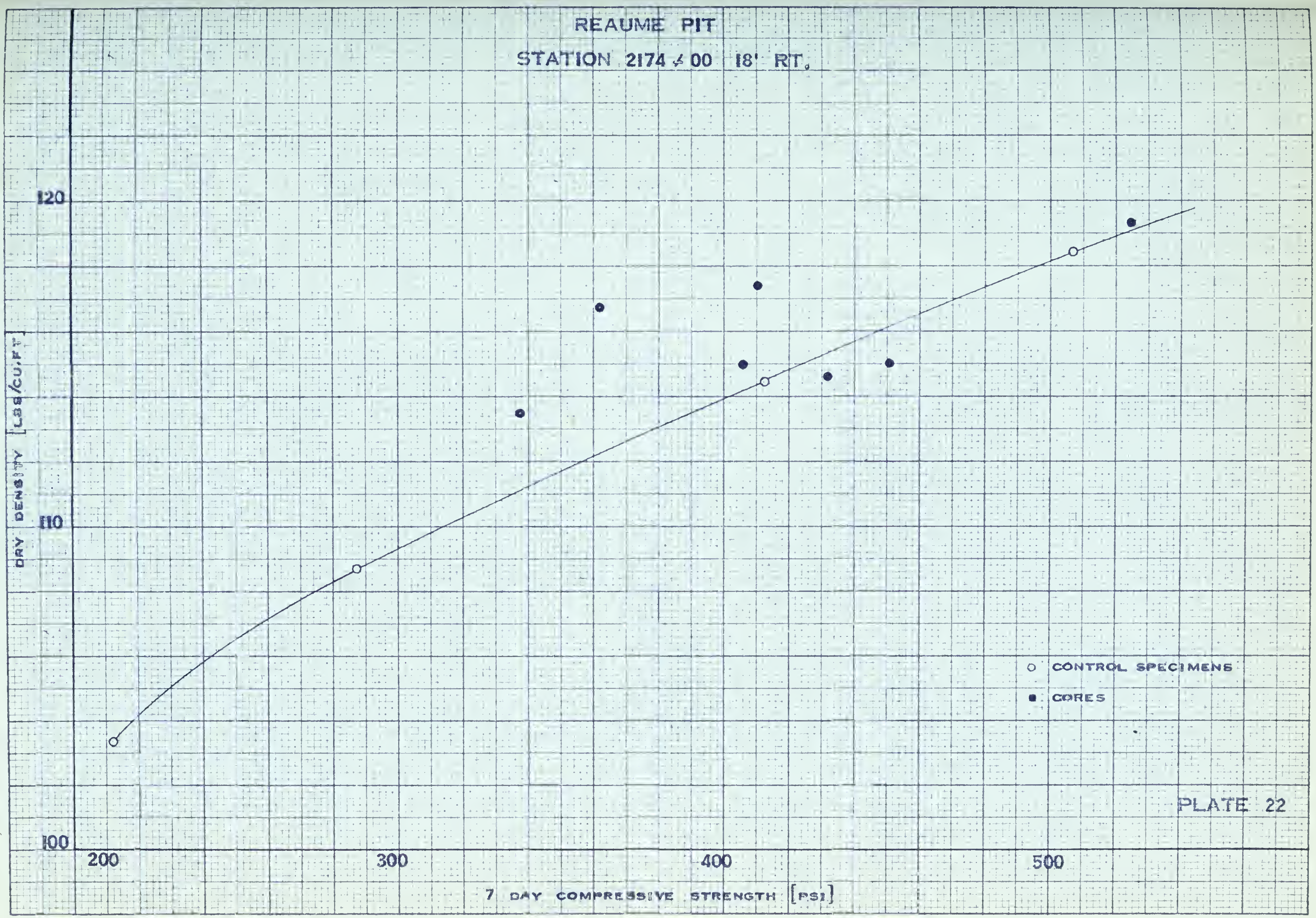
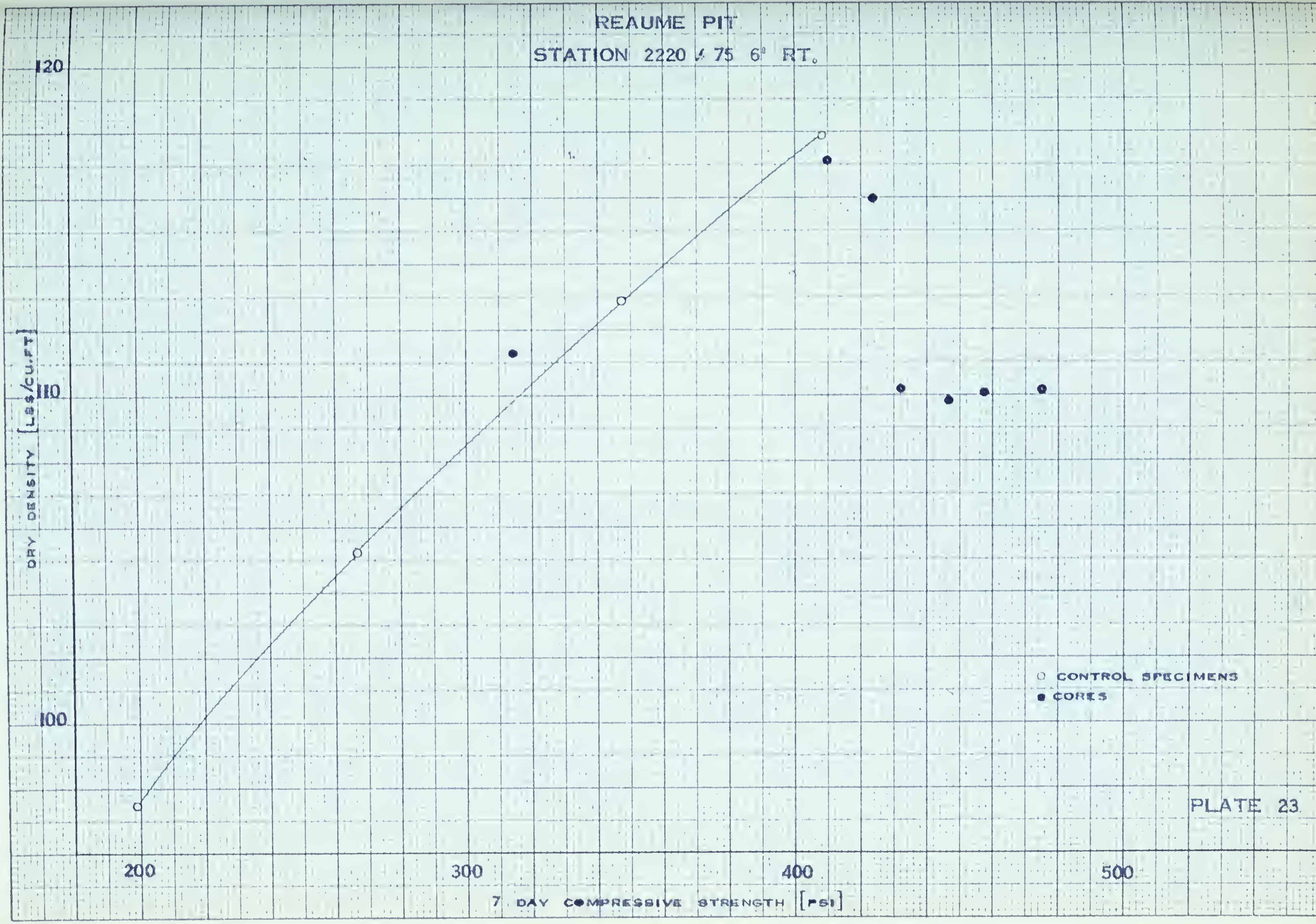
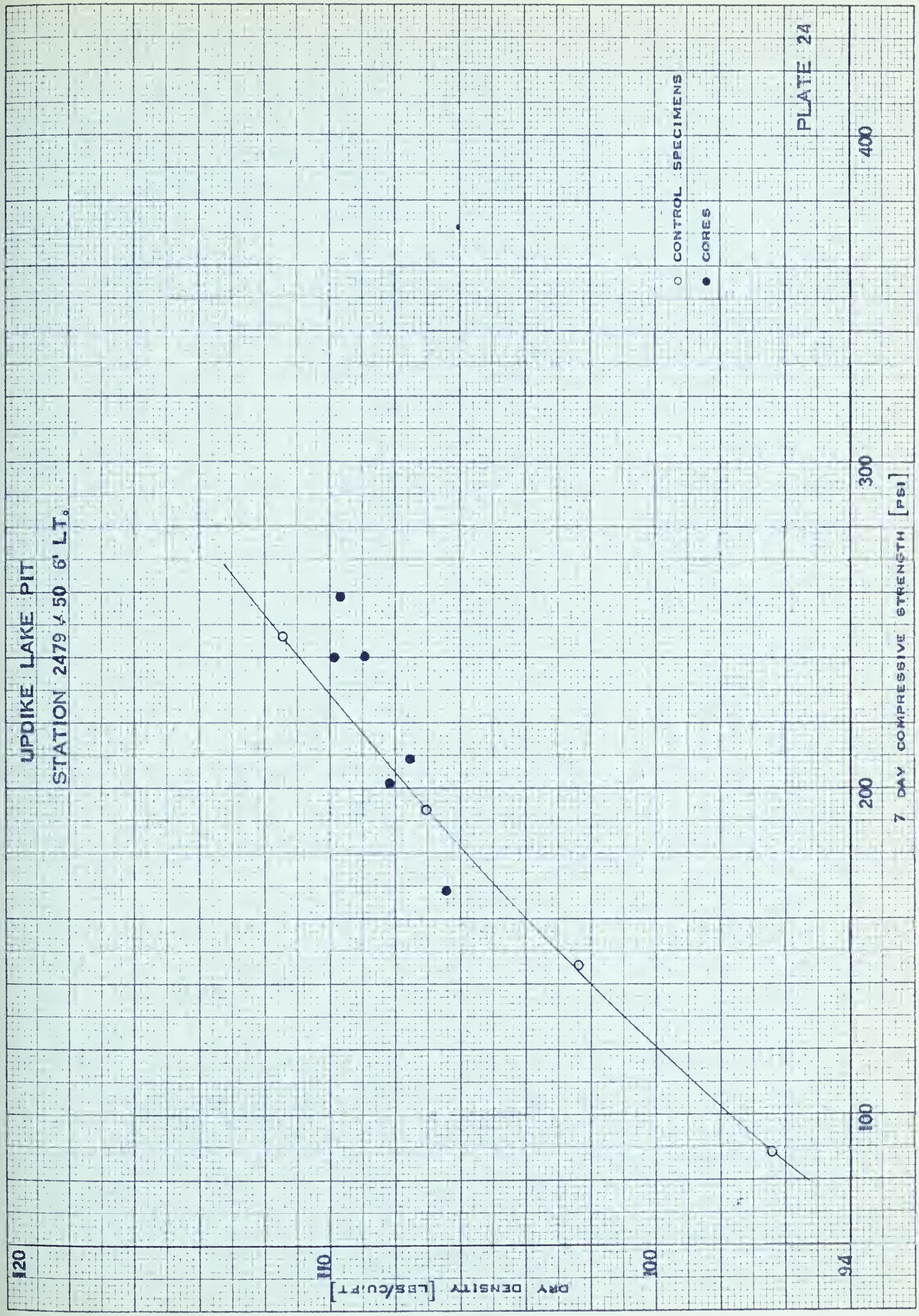

REAUME PIT
STATION 2115 + 90 6' LT.
120
110
100
DRY DENSITY [LBS/CU.FT]
200
300
400
500
7 DAY COMPRESSIVE STRENGTH [PSI]
○ CONTROL SPECIMENS
● CORES

PLATE 20


REAUME PIT
STATION 2173 + 35 6' LT.
120
110
102
DRY DENSITY [LBS/CU.FT]
200
300
400
500
7 DAY COMPRESSIVE STRENGTH [PSI]
O CONTROL SPECIMENS
● CORES
PLATE 21


REAUME PIT
STATION 2174 ≁ 00 18' RT.
120
110
100
200
300
400
500
DRY DENSITY [LBS/CU.FT]
7 DAY COMPRESSIVE STRENGTH [PSI]
○ CONTROL SPECIMENS
■ CORES
PLATE 22


REAUME PIT
STATION 2220 ≠ 75 6' RT.
120
110
100
DRY DENSITY [LBS/CU.FT]
200
300
400
500
7 DAY COMPRESSIVE STRENGTH [PSI]
○ CONTROL SPECIMENS
● CORES
PLATE 23


UPDIKE LAKE PIT
STATION 2479+50 6' LT.
○ CONTROL SPECIMENS
● CORES
PLATE 24
7 DAY COMPRESSIVE STRENGTH [PSI]
100
200
300
400
DRY DENSITY [LBS/CU.FT]
94
100
110
120

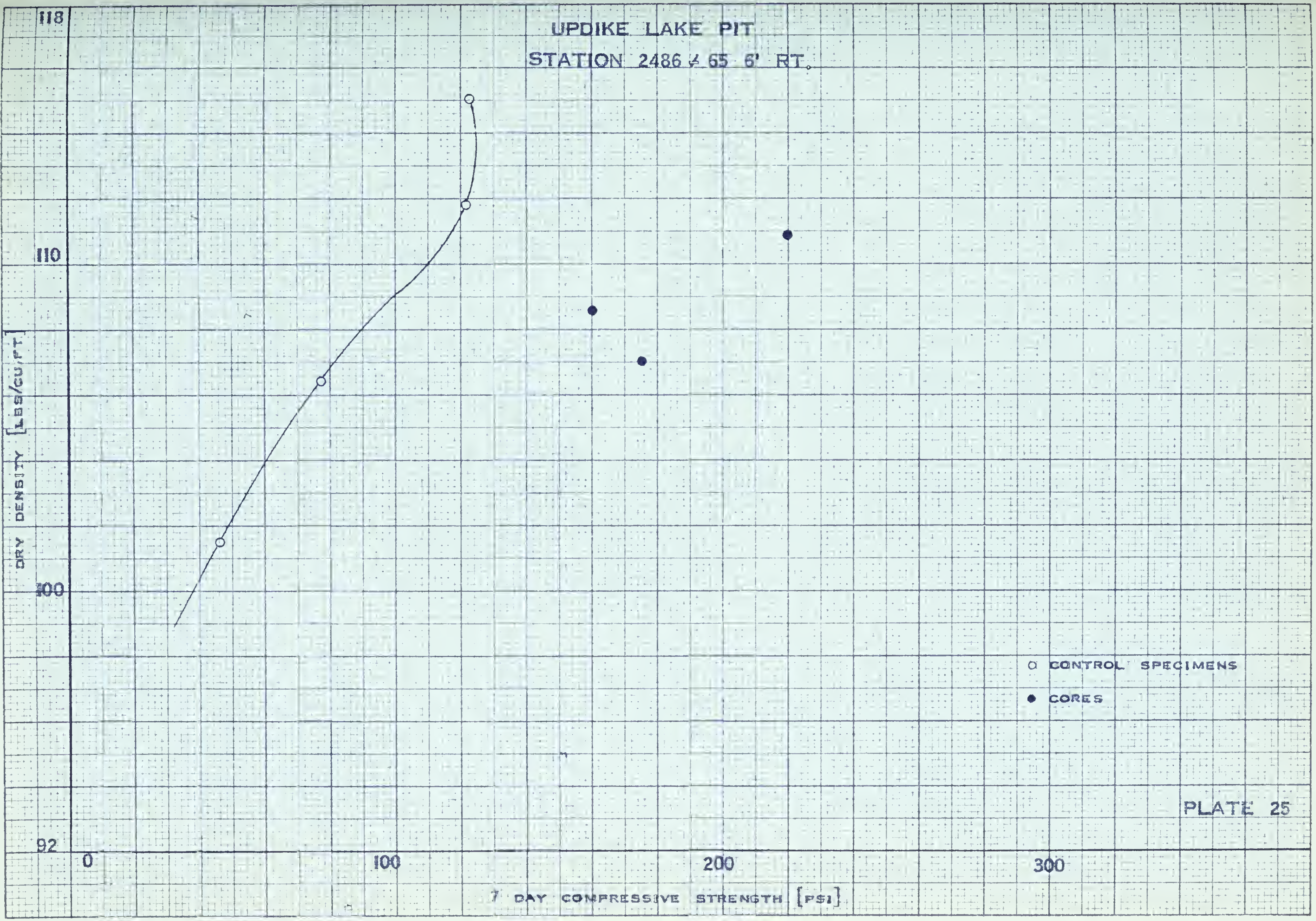
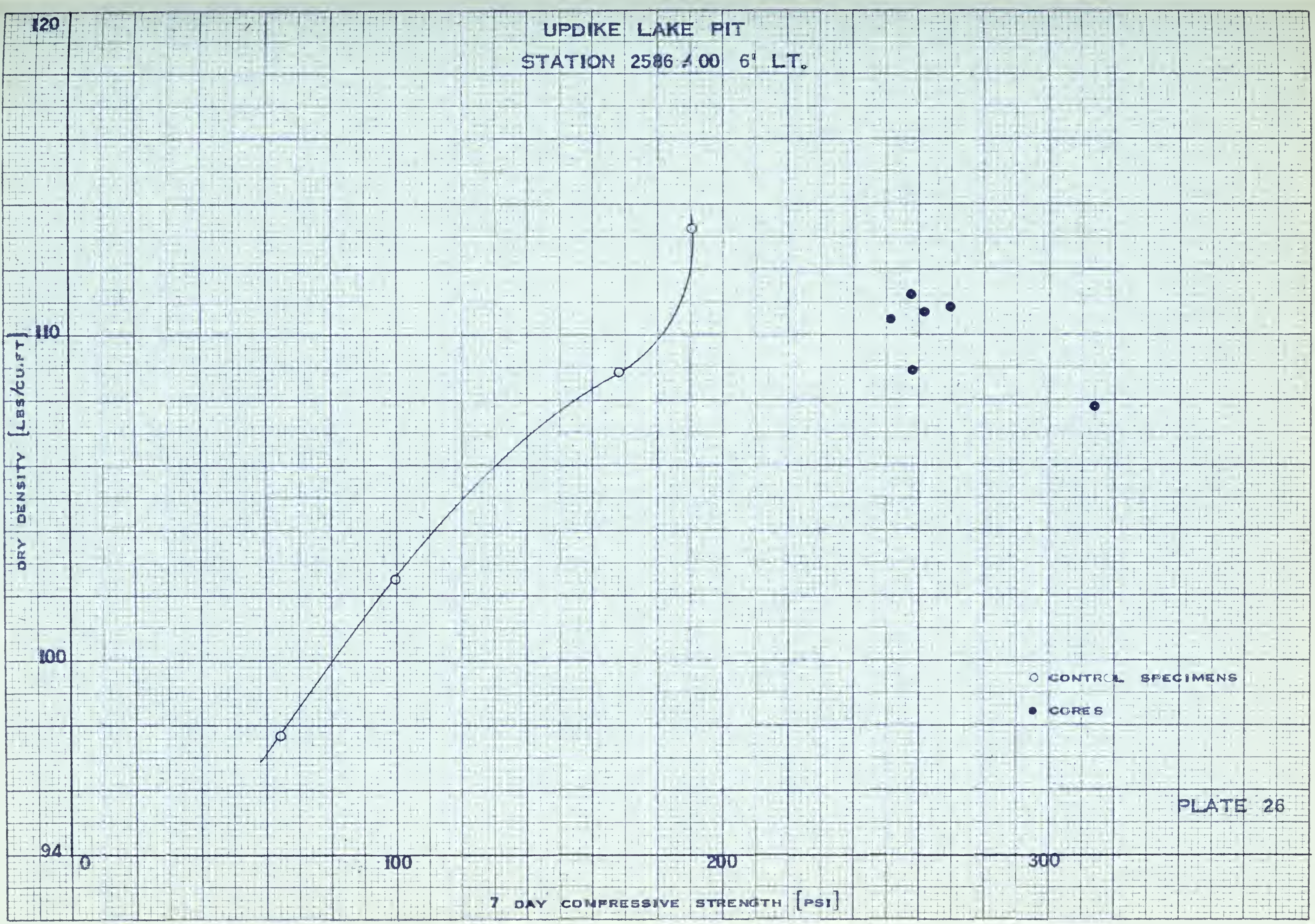
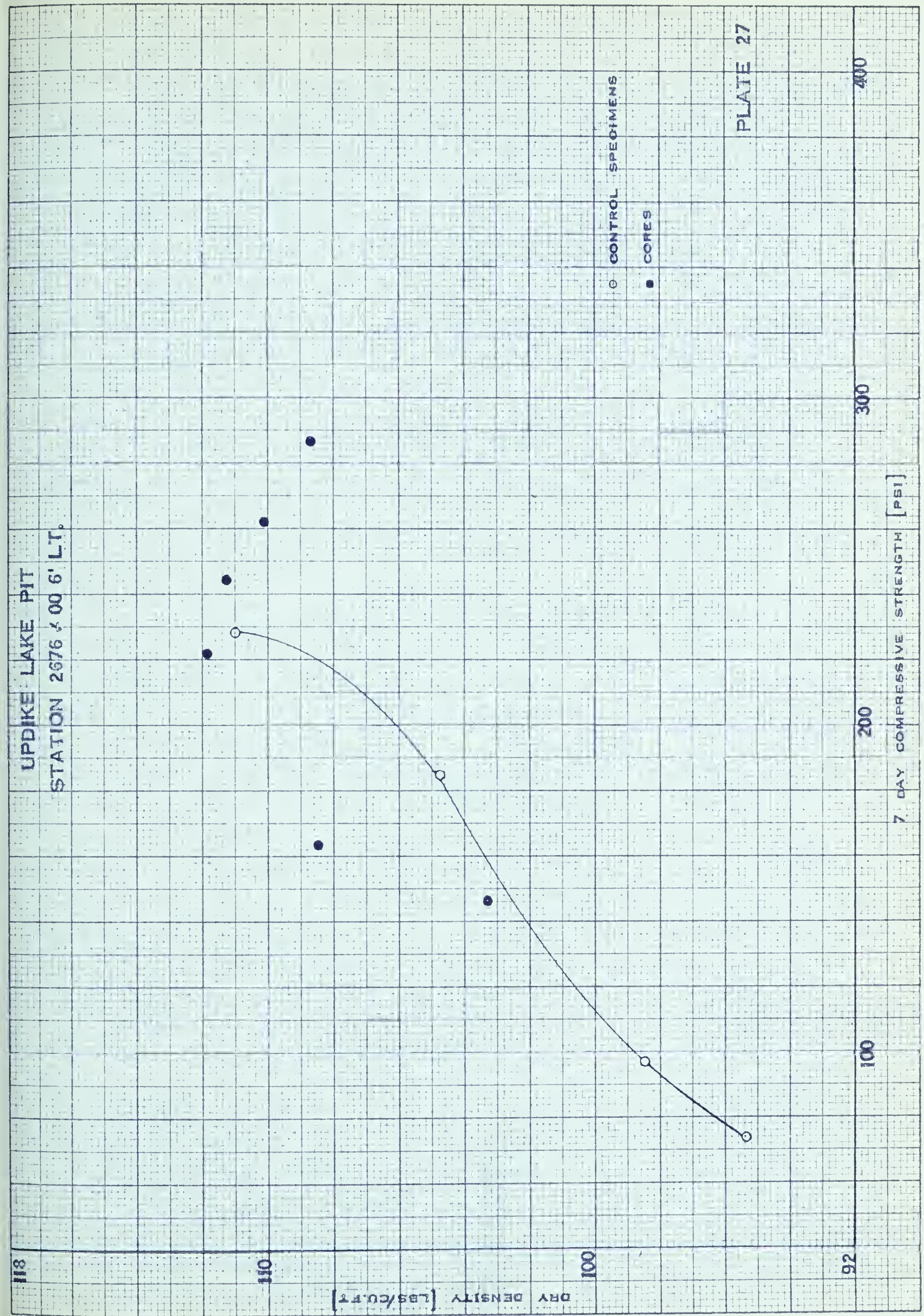
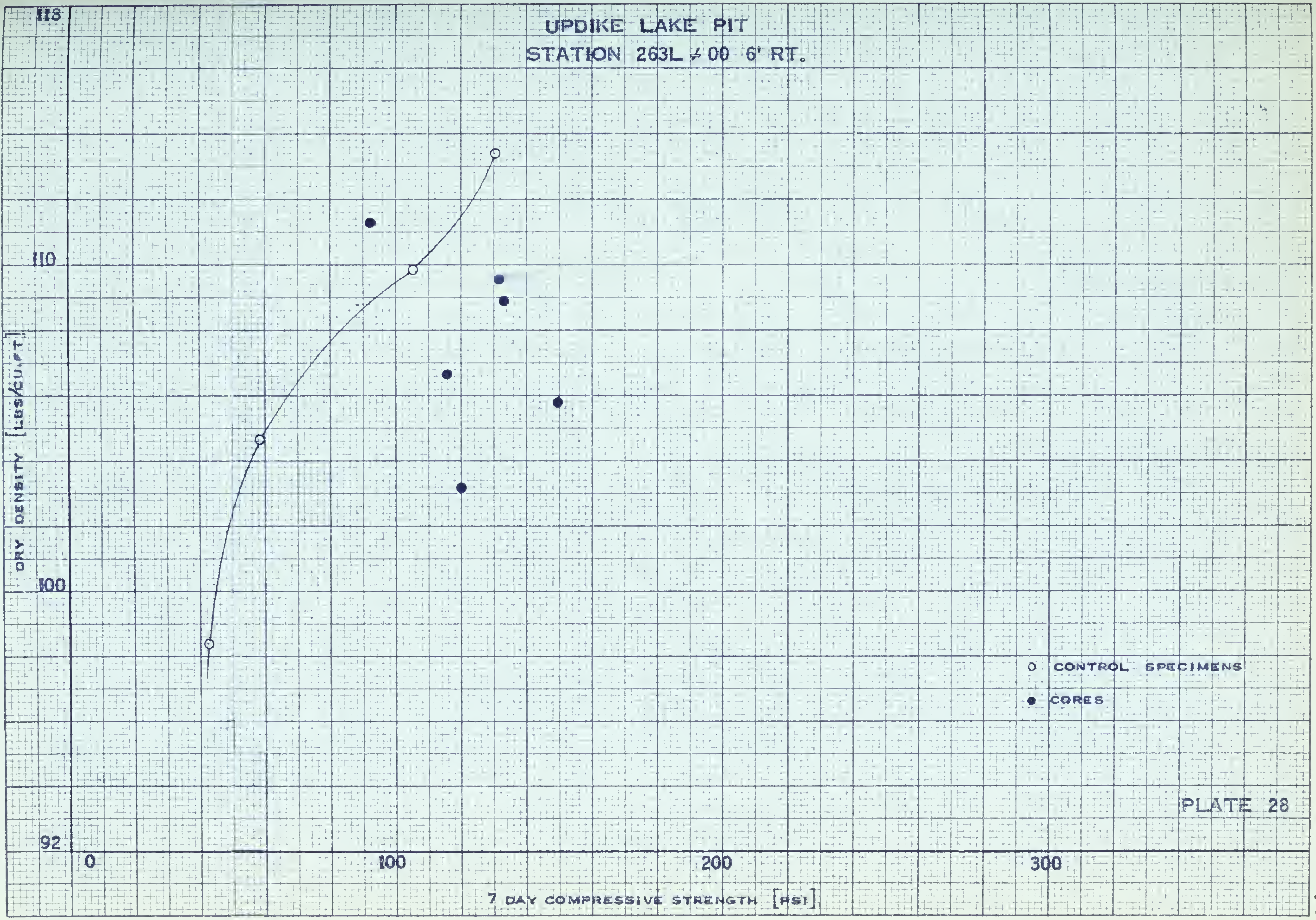
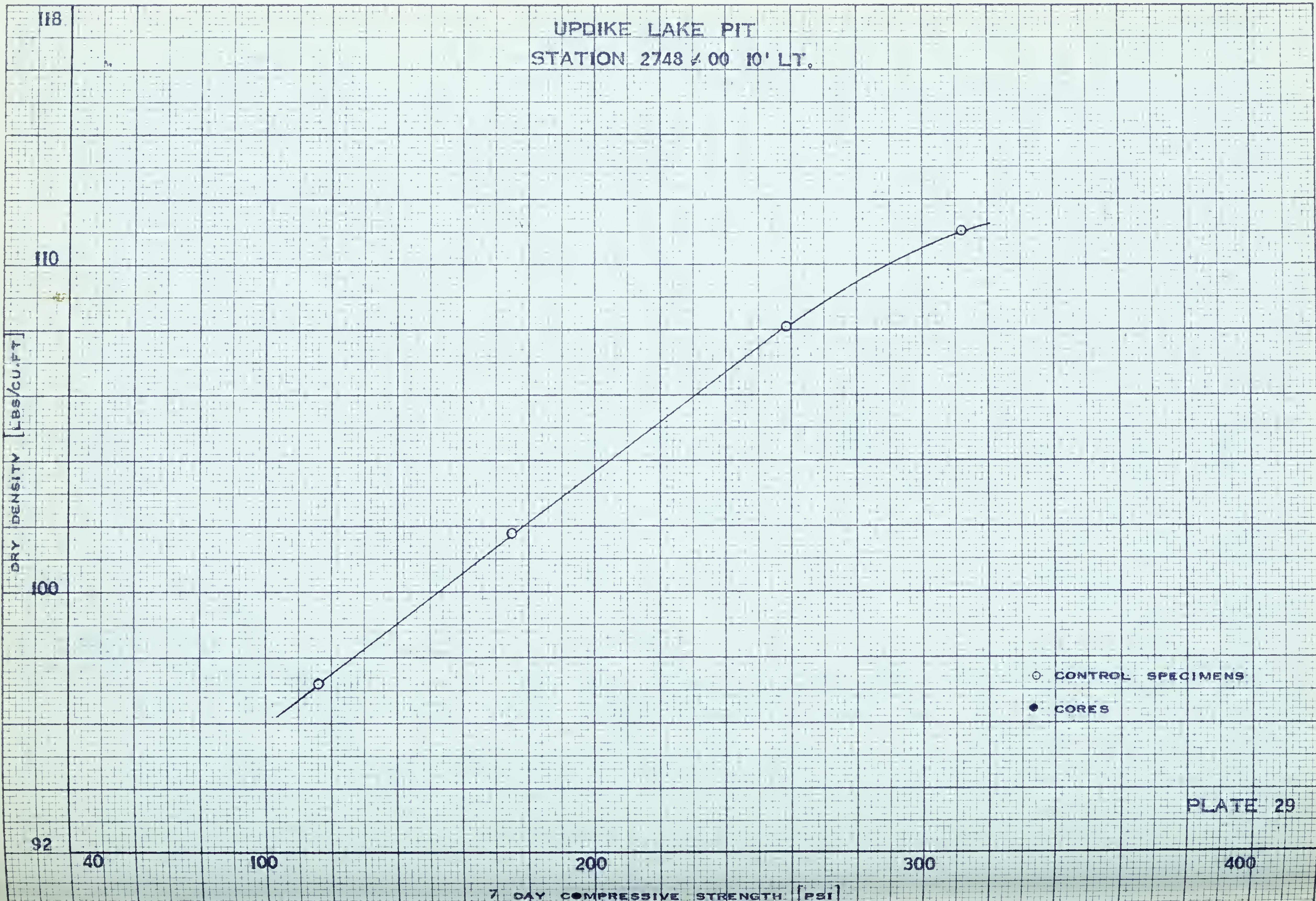

UPDIKE LAKE PIT
STATION 2486 + 65 6' RT.
118
110
100
92
DRY DENSITY [LBS/CU.FT]
0
100
200
300
7 DAY COMPRESSIVE STRENGTH [PSI]
○ CONTROL SPECIMENS
● CORES

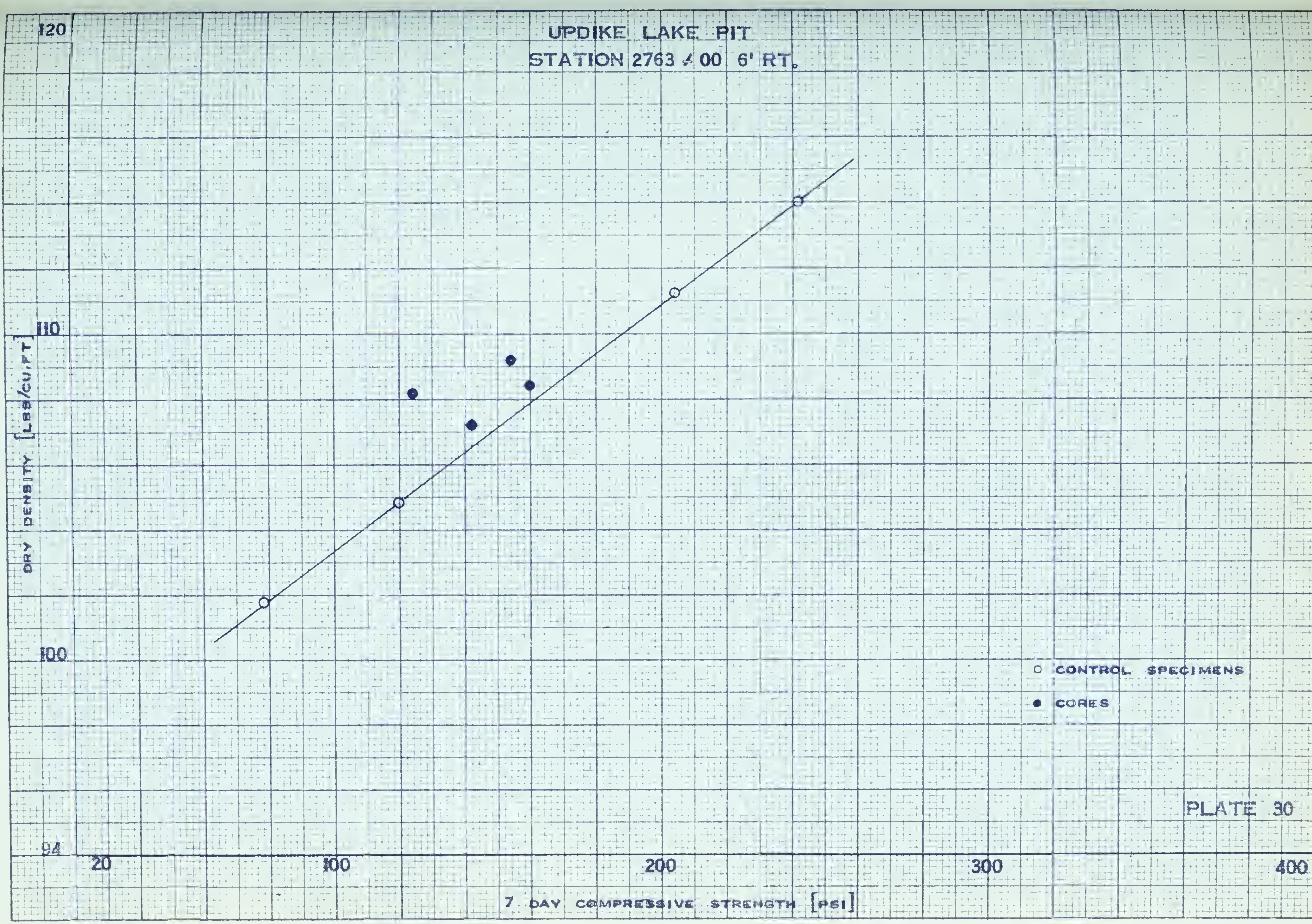
PLATE 25

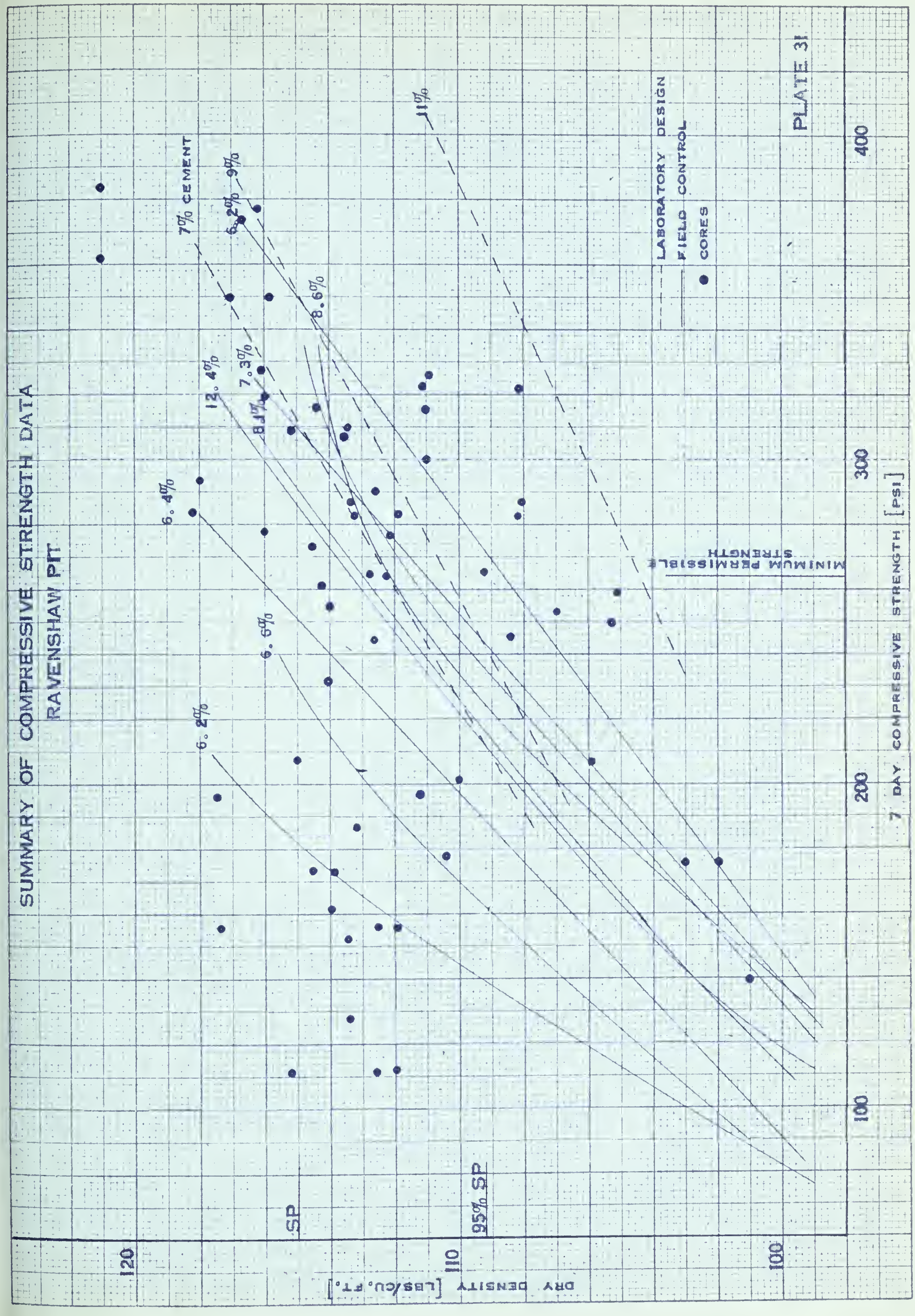

UPDIKE LAKE PIT
STATION 2586 + 00 6' LT.
120
110
100
94
DRY DENSITY [LBS/CU.FT]
0
100
200
300
7 DAY COMPRESSIVE STRENGTH [PSI]
CONTROL SPECIMENS
CORES
PLATE 26


UPDIKE LAKE PIT
STATION 2676 + 00 6' LT.
PLATE 27
CONTROL SPECIMENS
CORES
7 DAY COMPRESSIVE STRENGTH [PSI]
100
200
300
400
DRY DENSITY [LBS/CU.FT]
92
100
110
118


UPDIKE LAKE PIT
STATION 263L ≠ 00 6' RT.
118
110
100
92
DRY DENSITY [LBS/CU.FT]
0
100
200
300
7 DAY COMPRESSIVE STRENGTH [PSI]
O CONTROL SPECIMENS
● CORES
PLATE 28


UPDIKE LAKE PIT
STATION 2748 ≠ 00 10' LT.
DRY DENSITY [LBS/CU.FT]
118
110
100
92
40
100
200
300
400
7 DAY COMPRESSIVE STRENGTH [PSI]
CONTROL SPECIMENS
CORES
PLATE 29


UPDIKE LAKE PIT
STATION 2763 + 00 6' RT.
120
110
100
94
DRY DENSITY [LBS/CU.FT]
20
100
200
300
400
7 DAY COMPRESSIVE STRENGTH [PSI]
○ CONTROL SPECIMENS
● CORES
PLATE 30


SUMMARY OF COMPRESSIVE STRENGTH DATA
RAVENSHAW PIT
PLATE 31
LABORATORY DESIGN
FIELD CONTROL
CORES
MINIMUM PERMISSIBLE STRENGTH
7% CEMENT
6.2%
9%
11%
8.6%
7.3%
13.4%
8.1%
6.4%
6.6%
6.2%
SP
95% SP
100
200
300
400
7 DAY COMPRESSIVE STRENGTH [PSI]
120
110
100
DRY DENSITY [LBS/CU.FT.]

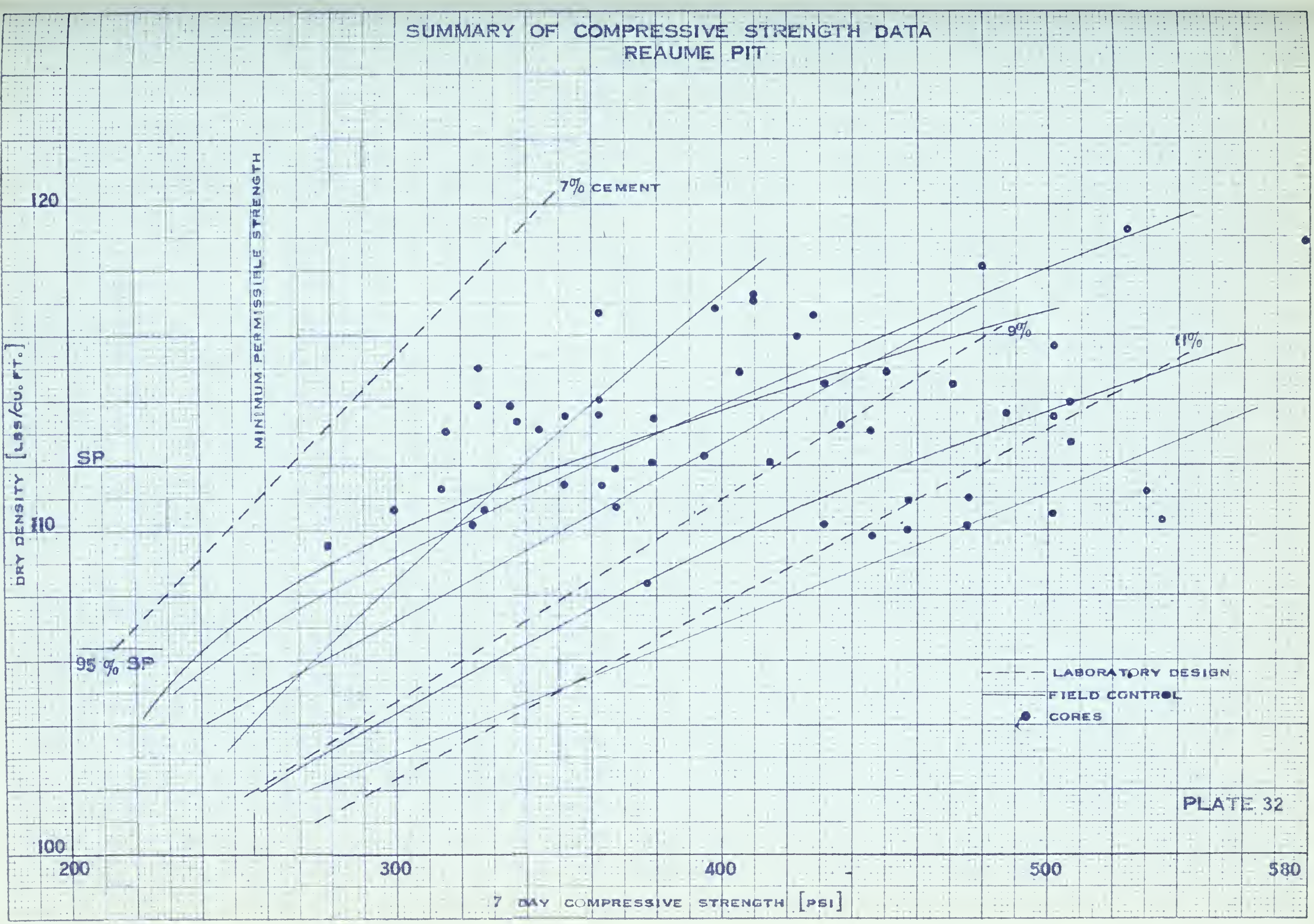

SUMMARY OF COMPRESSIVE STRENGTH DATA
REAUME PIT
7% CEMENT
9%
11%
MINIMUM PERMISSIBLE STRENGTH
SP
95 % SP
120
110
100
200
300
400
500
580
DRY DENSITY [LBS/CU. FT.]
7 DAY COMPRESSIVE STRENGTH [PSI]
LABORATORY DESIGN
FIELD CONTROL
CORES

PLATE 32

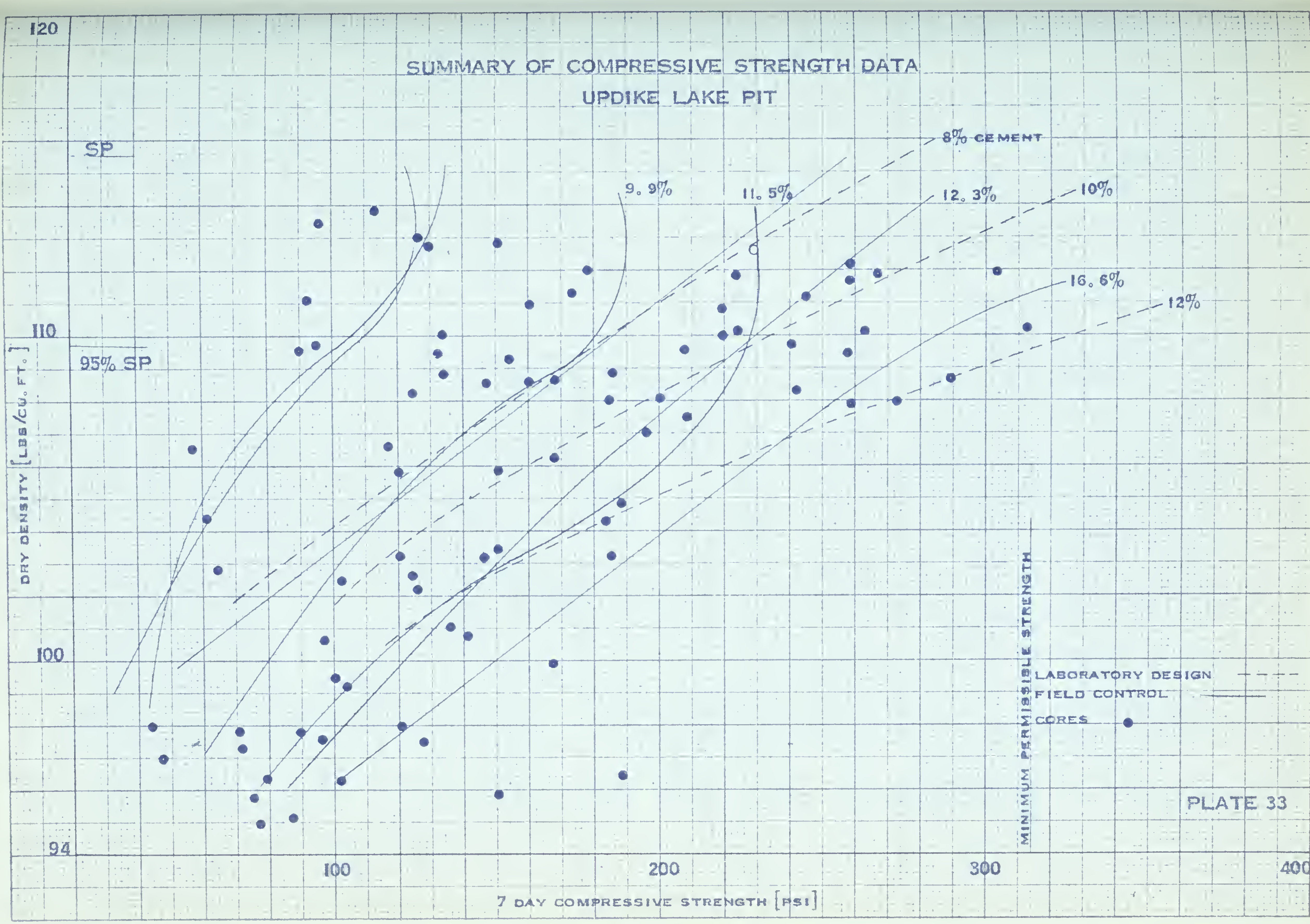

SUMMARY OF COMPRESSIVE STRENGTH DATA
UPDIKE LAKE PIT
SP
95% SP
8% CEMENT
9.9%
11.5%
12.3%
10%
16.6%
12%
MINIMUM PERMISSIBLE STRENGTH
LABORATORY DESIGN
FIELD CONTROL
CORES
DRY DENSITY [LBS/CU. FT.]
120
110
100
94
100
200
300
400
7 DAY COMPRESSIVE STRENGTH [PSI]

PLATE 33

The comparison of core strengths with control strengths (Plates 10 to 30) indicated close agreement in some instances and discrepancies in others. There was no consistency in the relation of core strengths to control strengths.

In some cases the core strengths plotted to the left of the density-strength curves, thus indicating a lower average strength, while in others the reverse was true. Because of the inconsistencies, a direct comparison of individual core strengths with the respective control strengths was not made. The following is a summary of the relation between the average core strengths and the corresponding control strengths.

	Plate No. Corresponding to the Strength Relation		
Pit	Core > Control	Core=Control	Core < Control
Ravenshaw	10,14	11,13,17	12,16,18
Reaume	19,23	20,21,22,24	19a
Updike Lake	25,26,28	27,30	

Thus in seven instances the average strength of the cores was greater than the corresponding control strength, was the same in nine instances, and was less in four. The reason for the discrepancies could only be determined by an analyses of the grain-size distribution, and the cement content of each core. Although the cores were taken from areas which the control strengths represented, there still existed the possibility of variations in gradation of the material and in the cement content.

The density-strength curves of Plates 31, 32, and 33, denote the range in strengths that could be expected at densities

lying between 95 and 100 percent standard Proctor. The ranges in strength corresponding to the various pits are:

Pit	Range in strengths(psi)	% Variation
Ravenshaw	140 to 340	145
Reaume	240 to 520	120
Updike Lake	100 to 360	260

In the laboratory investigation, the variations in strength corresponding to a five percent variation in density, and a four percent variation in cement content (plus and minus two percent of the design cement content) were:

Pit	Range in strengths(psi)	% Variation
Ravenshaw	210 to 490	135
Reaume	186 to 426	130
Updike Lake	186 to 500	170

With the exception of Reaume, the ranges in strength obtained in the field were higher than those established by the laboratory investigation. This is partly due to the larger range in cement contents used in the field. The ranges in cement contents used in the field were; 6 to 12 percent, 9 to 15 percent, and 8 to 21 percent, for Ravenshaw, Reaume, and Updike Lake respectively. (See Mixing Uniformity Chapter 5). Another contributing factor may have been the variations in the gradation of the soils. On the basis of the preceding results, it is concluded that if proper control is exercised over such variables as cement content, gradation, and density, the engineering properties of the soil-cement produced in the laboratory, can be duplicated in the field.

In the case of Ravenshaw material there appeared to be very little agreement between the field and the laboratory density-strength curves (Plate 31). The general slope of the field density-strength curves was steeper than that of the design curves. This discrepancy could be contributed to a difference in gradation. The Ravenshaw material varied considerably in gradation throughout the borrow pit. The material used in the laboratory was prepared by mixing several samples obtained from different locations within the pit, and so represented an average gradation. This average gradation was not representative of the actual gradation used in the field. At the time of the laboratory investigation it was not known to what degree the various materials in the borrow pit would be mixed.

Because of the variations in gradation, the positions of the various field density-strength curves could not be properly analyzed on the basis of cement content alone. An attempt to analyze them on the basis of cement content and uniformity coefficient was made, the results of which are given under the section Uniformity of Gradation of this chapter.

There appeared to be better agreement between the field and laboratory density-strength curves in the case of the Reaume material. The cement content corresponding to the individual curves was not determined, and so the relative positions of the field and design curves could not be evaluated.

The shape of the field density strength curves corresponding to the Updike Lake material, were such as to make it appear as if there was little agreement with the design curves.

The reversal of the curves was brought about by the breakdown of the sandstone under compaction. The amount of breakdown was affected by the gradation of the material. In the laboratory investigation, a considerable amount of material was taken and thoroughly mixed to provide a good uniform gradation. In the field, only as much material was taken as was required to form the specimens. As a result there may have been an excess of large sandstone particles, rendering poor gradation, the consequence of which would be a material highly susceptible to breakdown, under the impact of the compacting hammer. The position of the portions of the field density-strength curves below the point at which there began a reversal of curvature, were in good agreement with the laboratory curves as based on cement contents.

A comparison of the core strengths with the minimum permissible compressive strengths as set out by the Portland Cement Association criteria, showed that:

1. Approximately fifty percent of the Ravenshaw core strengths were below the permissible strength.
2. Practically all of the Reaume core strengths were above the permissible strength.
3. The majority of the Updike Lake core strengths were below the permissible strength.

The low strengths can be attributed to low cement contents and low densities. An example of the effects of low cement contents is illustrated by Plate 31. The densities were between 100 and 95 percent Proctor but the cement contents were

generally below the design value (9%). Plate 33 illustrates the effects of low densities. The cement content was generally higher than the design value (10%) but because of the low desnities the majority of the strengths were well below the minimum permissible strength.

TABLE 10

COMPARISON OF CORE STRENGTHS WITH CONTROL STRENGTHS

Elhardt Pit

	CONTROL SPECIMENS			CORES	
Location	No.	Dry Density (lbs/cu.ft)	Compressive Str. (psi)	No.	Compressive Str. (psi)
1576+00	E- 1	120.3	260		
15' Lt.	E- 2	118.5	251		
	E- 3	117.5	164		
1584+00	E- 5	120.9	192		
5' Lt.	E- 6	120.2	192		
1598+50				EC-1	239
18' Lt.				EC-2	194
				EC-3	257
				EC-4	187
				EC-5	198
				EC-6	173
1613+00					
18' Lt.				EC-7	256
				EC-8	289
				EC-9	313
1626+00				EC-10	170
18' Lt.	E-14	118.2	210	EC-11	154
	E-15	118.0	192	EC-12	154

1643+00 6' Lt.	E-16	118.5	215	EC-13	244
	E-18	117.5	231	EC-14	242
	E-20	117.8	198	EC-15	258
1657+00 6' Lt.	E-23	112.2	298	EC-19	176
	E-24	121.3	287	EC-20	171
	E-27	119.7	220	EC-21	291
1660+00 6' Lt.	E-29	120.8	355	EC-25	262
	E-31	119.8	252	EC-27	212
	E-33	120.3	281	EC-29	280
1589+00 18' Rt.	E-41	120.3	399	EC-40	315
	E-43	119.0	304	EC-41	310
	E-45	117.8	292	EC-42	278
1623+00 6' Rt.	E-53	117.8	278	EC-52	269
	E-55	117.0	251	EC-53	261
				EC-54	310
1637+50 6' Rt.	E-59	117.7	366	EC-58	335
	E-61	116.8	350	EC-59	366
	E-63	116.2	360	EC-60	349

SUMMARY OF RESULTS

Location	Average Compressive Strength(psi) Control Specimens	Cores	%Core Strength / Control Strength
1576+00	225	---	---
1584+00	192	---	---
1598+50	---	208	---
1613+00	---	286	---
1626+00	201	159	79
1643+00	215	248	115
1657+00	268	213	80
1660+00	296	251	85
1589+00	331	201	62
1623+00	264	280	106
1637+50	359	350	98
Average	261	244	89
Range	192-359	159-350	62-115

Average cement content = 6%

From the laboratory density-strength relationship (Plate 1a)

Design strength: (6% cement, Std. Proctor) = 266 psi

Range: (95% Std. Proctor, 4% cement to 100% Std. Proctor and 8% cement) = 100-385 psi

Average: (97.5% Std. Proctor, 6% cement) = 230 psi

Minimum permissible strength (Fig. 38 Short Cut Test Proc. Appendix 1) = 256 psi

In the case of the Elhardt material, the densities of the cores were not determined, and so the correlation was made on the basis of strength and cement content. The density range was taken as 95 to 100 percent standard Proctor in accordance with the specifications. The average cement content used in the field was six percent, as based on daily plant calibrations. Three samples of soil-cement were analyzed for cement content and the values thus determined were, 4.9, 5.3 and 7.1 percent. The average of the three was 5.7 percent and so six percent was used as an average value. Since specifications allowed a two percent variation in cement content, a range of four to eight percent was selected as the cement content limits.

The limits of strength, as established by the density-strength relationship (Plate 1a), were therefore the strength corresponding to 95 percent standard Proctor and four percent cement (lower limit = 100 psi), and the strength corresponding to 100 percent Standard Proctor and eight percent cement (upper limit = 385 psi). The average strength was that corresponding to 97.5 percent standard Proctor and six percent cement (230 psi). The core strengths were within the above range and the average core strength (244 psi) was almost identical to the above average. Therefore it can be concluded that the strength of the soil-cement produced in the field was in accordance with the values predetermined in the laboratory.

The average strength of the cores was approximately ten percent lower than the design value (266 psi). The significance

of this ten percent decrease, was that it lowered the average strength below the minimum permissible (256 psi), as set out by the Portland Cement Association criteria.

The range in strengths of the field control specimens was slightly higher than that of the cores. The average strength of the control specimens was also higher. The reason for this was that the densities of the control specimens were very near standard Proctor whereas the densities of the cores ranged from 95 to 100 percent standard Proctor.[1] It is also for this reason, that the average strength of the control specimens was almost identical to the design strength (261 versus 266 psi) at six percent cement.

---

1 Based on field densities determined for construction control (Sand Cone Method).

FREEZE-THAW TESTS ON SOIL-CEMENT CORES

Cores were taken in groups of six from any one location in the field. Three of the cores were used for determining compressive strengths. The other three were shipped to the provincial highway laboratory for freeze-thaw tests. In most instances the cores underwent 12 freeze-thaw cycles after which their compressive strengths were determined. These cores were not brushed after each cycle of freezing and thawing, and so could not be used as a direct measure of the ability of the soil-cement to withstand the stresses set up by expansion and contraction. However, in some cases the cores disintegrated completely or to such an extent that it was quite evident that the material could not withstand the forces brought about by freezing and thawing. Such cores and their respective locations are given in Table II. Some cores underwent the standard A.S.T.M. Freeze-Thaw Test and these cores were also listed in the table along with their respective location and the soil-cement loss.

In addition, the average seven day compressive strength of the other three cores taken at locations corresponding to the above cores, were included in this table.

The criteria for minimum permissible compressive strength, and maximum permissible soil-cement loss, are included in the table.

TABLE II

SOIL-CEMENT LOSSES AND SEVEN DAY COMPRESSIVE STRENGTHS OF CORES TAKEN FROM THE SAME LOCATION

ELHARDT PIT

Location	Core No.	Soil-Cement Loss (%)	Av. 7-day Comp.Str.(psi)
1643+00 6' Lt.	EC-16 EC-17 EC-18	Specimens broke down during F-T cycles	246
1657+00 6' Lt.	EC-22 EC-23 EC-24	Specimens broke down during F-T cycles	213
1597+60 18' Rt.	EC-43 EC-44	Specimens broke down during F-T cycles	
1623+00 6' Rt.	EC-49 EC-50 EC-51	Specimens broke down during F-T cycles	267

Criteria:

Minimum permissible 7 day compressive strength = 256 psi

Maximum permissible soil-cement loss = 14%

Note: No cores were brushed in accordance with the A.S.T.M. Freeze-Thaw Test Procedure.

RAVENSHAW PIT

Location	Core No.	Soil-Cement Loss (%)	Av. 7-day Comp.Str.(psi)
1685/10 6' Rt.	RaC- 1	☆	---
1657/50 6' Rt.	RaC-19	☆	---
1738/50 6' Lt.	RaC-13	☆	---
1783/50 18' Lt.	RaC-43	☆	207
1819/00 18' Lt.	RaC-49	25	266
1809/20 18' Lt.	RaC-55	29	285
1882/25 18' Lt.	RaC-85	☆	245
1885/00 18' Lt.	RaC-91	☆	158
1785/00 18' Lt.	RaC-139	☆	200
1984/00 6' Rt.	RaC-235	17.6	284
2040/40 18' Rt.	RaC-241	☆	203
2047/00 18' Rt.	RaC-247	☆	132

☆ Cores broke down during the freeze-thaw test

Balance of cores were brushed after the last freezing cycle only.

Criteria:
Minimum permissible strength = 264 psi
Maximum permissible soil-cement loss = 14%

UPDIKE LAKE PIT

Location	Core No.	Soil-Cement Loss (%)	Av. 7-day Comp.Str.(psi)
2360+00 6' Lt.	UC- 31	5	500
2310+64 6' Rt.	UC- 37	3	501
2322+40 18' Rt.	UC- 43	3	464
2344+46 3' Rt.	UC- 49	*	238
2408+75 6' Rt.	UC- 73	15	283
2440+45 6' Rt.	UC- 85	26	359
2479+50 6' Lt.	UC- 91	*	205
2469+13 18' Rt.	UC-103	*	185
2519+60 18' Rt.	UC-112	25	163
2584+43 6' Rt.	UC-133	*	121
2676+00 6' Lt.	UC-142	*	177
2730+77 6' Lt.	UC-166	*	183
2763+00 6' Rt.	UC-175	*	133

* Cores broke down during the freeze-thaw test.

Criteria:
Minimum permissible strength = 314 psi
Maximum permissible soil-cement loss = 14%

REAUME PIT

No cores were brushed in accordance with the A.S.T.M. Freeze-Thaw Test procedure. None of the cores which underwent the 12 cycles showed signs of disentegrating. Practically all core strengths were well above the minimum permissible strength.

Since only a few cores underwent the standard procedure for determining the soil-cement loss under the action of freezing and thawing, the results are somewhat limited. The majority of the cores were subjected to freeze-thaw tests without brushing after each cycle, after which the compressive strength was determined. Since there is no criteria as to what the compressive strength should be following twelve cycles of freezing and thawing, the results could not be analyzed. The only use that could be made of such tests was when the cores disintegrated under the action of freezing and thawing. This was a definite indication of an inadequate mixture. However, the criteria for soil-cement loss was fourteen percent for the material used, and so disintegration only indicated the very weak cores. Where this occurred and where the standard procedure was used, the average strength of the cores taken from the same area was given, in order to determine whether or not compressive strength alone could be used as the criterion. In most instances where the cores disintegrated under the freeze-thaw action, the average strength of the cores taken from the same area, was below the permissible strength as given by the Portland Cement Association criteria.

There were a few instances in which the soil-cement loss was greater than the stipulated criteria, and the average compressive strength of the corresponding cores was higher than the minimum permissible strength. Since only one specimen was brushed out of a group of six it is quite possible that a specimen weaker than the average was used to determine the soil-cement loss.

The majority of the results indicated that when the compressive strength of the soil-cement was below the minimum permissible value as set out by the Portland Cement Association criteria, the soil-cement loss as determined by the freeze-thaw test, was greater than the maximum permissible value stipulated. On the basis of this, the portions of the base course which exhibited low compressive strengths and high soil-cement losses, will not perform satisfactorily after considerable exposure to the elements, according to the Association's criteria. It is therefore most important that a continual observance of the performance of the soil-cement base course with time, be carried out. Sufficient information is available as to the locations of the portions of the base course that did not meet the Association's criteria. Periodic checks of these areas should be made and various tests should be conducted to determine whether or not the base course is retaining it's load carrying capacity. Tests such as the Unconfined Compression Test, the California Bearing Ratio Test, or the Plate Bearing Test could be used as a measure of the serviceability of the base course. Periodic determinations of the void ratio could also be used as an indication of the cements ability to hold the soil particles together. An appreciable increase in the void ratio would indicate that some of the bonding action had been destroyed.

MIXING UNIFORMITY

To determine the uniformity with which the cement was dispersed through the soil during the mixing cycle, several soil-cement samples were taken from one batch of material and the cement content of each sample was determined.*

The consistency with which the design cement content was maintained throughout the project, was investigated by taking soil-cement samples at random, and analyzing them for cement content.

The results are given in Table 12.

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* Laboratory Method For The Determination of the Cement Content of Cement-Stabilized Soils

TABLE 12

MIXING UNIFORMITY

A. Variations in cement content in any one batch

Group	Pit	Sample No.	Cement content(% by weight)
A	Reaume	1	10.8
		2	10.6
		3	10.4
B	Updike Lake	1	7.9
		2	8.9

B. Variations in cement content from time to time

ELHARDT PIT

Location		Cement Content (% by weight)
1594+90	6' Lt.	4.9
1616+82	1' Rt.	7.1
1645+40	13' Lt.	5.3

Range = 4.9 - 7.1%   Average = 5.7%

Design Value = 8%

RAVENSHAW PIT

Location		Cement Content (% by weight)
1965+25	18' Lt.	7.3
1792+70	6' Lt.	6.8
1884+40	18' Rt.	8.1
1923+50	6' Rt.	6.4
1989+60	6' Lt.	8.6
1962+00	6' Rt.	6.2

1842/60	18' Rt.	10.5
1882/25	18' Lt.	12.4
1712/86	7' Rt.	10.0
1765/61	18' Rt.	10.4
1791/94	8' Lt.	6.3

Range = 6.2 - 12.4%   Average = 8.1%

Design Value = 9%

REAUME PIT

Location		Cement Content (% by weight)
2115/90	6' Lt.	9.7
2154/85	6' Rt.	9.6
2174/85	6' Rt.	11.6
2186/77	18' Rt.	9.7
2206/82	20' Rt.	11.1
2206/84	18' Rt.	11.1
2220/75	6' Rt.	10.6
2239/18	8' Lt.	9.3
2273/25	18' Rt.	14.8

Range = 9.3 - 14.8%   Average = 10.4%

Design Value = 10%

UPDIKE LAKE PIT

Location		Cement Content (% by weight)
2316/27	18' Lt.	12.5
2345/00	8' Lt.	19.2
2366/82	3' Lt.	21.1

2397+72	7' Rt.	13.8
2423+74	9' Lt.	14.6
2477+14	18' Lt.	12.8
2479+50	6' Lt.	12.3
2586+00	18' Lt.	9.9
2631+00	6' Rt.	7.9
2676+00	6' Lt.	11.5
2748+00	18' Lt.	16.6
2529+94	4' Lt.	12.8
2556+37	18' Rt.	10.4
2583+78	15' Lt.	15.8
2690+58	8' Lt.	15.8
2714+69	15' Rt.	9.6

Range = 7.9 - 21.1% Average = 13.3%

Design Value - 10%

The results of the investigation of the mixing uniformity achieved in the field indicated;

1. The cement was fairly uniformly dispersed through the soil during the mixing cycle. The maximum difference between cement contents in any one batch was one percent. This represented a deviation of half a percent from the average.
2. There was a considerable deviation in the cement content from time to time. The deviation ranged from 2.9 percent (Elhardt), to 13.2 percent (Updike Lake). The average cement content was the same as the design cement content in one instance only (Reaume).

Not being able to maintain a stipulated cement content, was in the author's opinion, the most significant factor in the production of inferior soil-cement, in the field. The problem appeared to lie in the method of proportioning the soil and the cement. The two materials were proportioned on a volumetric basis. The proportioning by weight would only remain constant if the dry unit weight of the soil remained unchanged. A change in the dry unit weight of the soil could occur as the result of;

1. Variations in moisture content of the soil.

Example: air dry soil versus soil with sufficient moisture to cause bulking.

2. Variations in the compacted state of the soil.
3. Variations in the gradation of the soil.

UNIFORMITY OF GRADATION

Preliminary soil surveys of the Ravenshaw borrow pit indicated a considerable variation in the gradation of the material. An attempt was made to determine the effects of variations in gradation on the field density-strength curves. This was done by taking samples of the raw soil that corresponded to the soil-cement material which was used to establish the density-strength relationship, and obtaining the gradation of the soil samples. The uniformity coefficient of each soil was determined by extrapolating the gradation curve. The various density-strength curves, the corresponding uniformity coefficients, and the cement contents are illustrated by Plate 34.

EFFECTS OF CEMENT CONTENT AND UNIFORMITY COEFFICIENT ON DENSITY-STRENGTH RELATIONSHIP

RAVENSHAW PIT

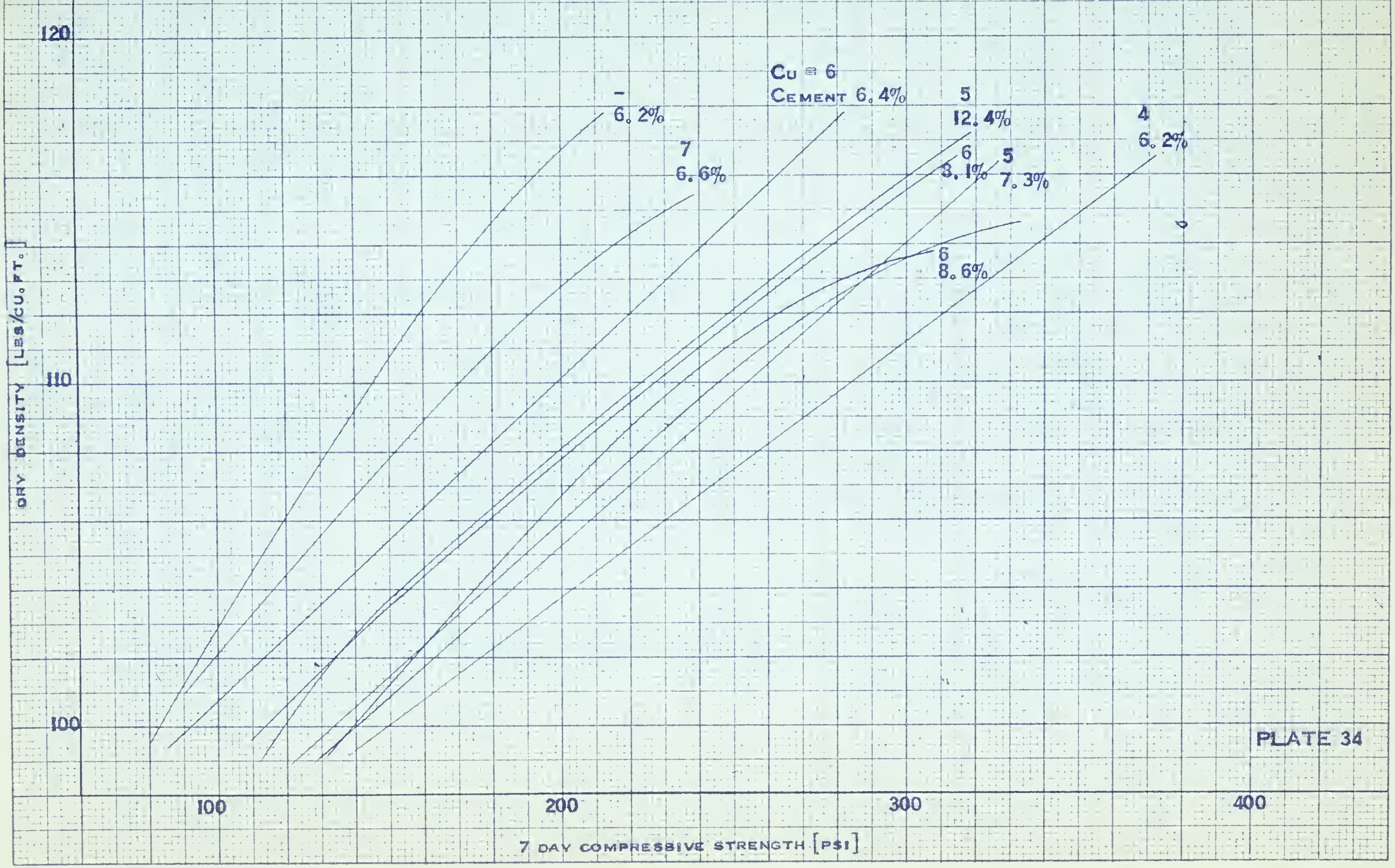

PLATE 34

Assuming the results of the laboratory investigation of the effects of uniformity coefficient on the density-strength relationship are correct, the positions of the various field density-strength curves (Plate 34) may be explained on this basis. For example, taking the three curves at approximately the same cement content (6.6, 6.4 and 6.2) their positions relative to each other would be determined by their uniformity coefficients. It was found in the laboratory investigation that for a constant cement content and density, the density-strength curves were displaced laterally so as to yield a greater compressive strength, as the uniformity coefficient decreased. The three curves at a cement content of approximately six percent are similarly located with respect to each other.

By the same token the position of the curve corresponding to a cement content of 7.3 percent and having a uniformity coefficient of five could very well lie to the right of the curves having a cement content of 8.1 and 8.6 percent but having a uniformity coefficient of six.

On this basis the curve corresponding to a uniformity coefficient of five and a cement content of twelve percent is not consistent with the rest. It would appear that the cement content is incorrect.

The above explanation of the positions of the various field density-strength curves, is only offered as a possibility. It cannot be considered conclusive on the basis of the amount of information available and the accuracy with which the results were obtained. For example, only one cement content was obtained

for each curve. Moreover the cement content was determined from a core taken from an area which supposedly represents the material used in establishing the density-strength relationship. The author's object of this phase of investigation, was merely to ascertain whether or not the uniformity coefficient of sands, which are essentially of the same classification, affect the density-strength relationship.

CONCLUSIONS OF FIELD INVESTIGATION

The following conclusions regarding the construction of a soil-cement base course have been made on the basis of the sands investigated.

1. The engineering properties of soil-cement produced in the laboratory, can be duplicated in the field, providing proper control is exercised over gradation, cement content, and density.
2. Compressive strength can be used as the criterion of the ability of soil-cement to withstand exposure to the elements, as defined by the freeze-thaw test.
3. Little difficulty is encountered in dispersing cement uniformly, through sandy soils.
4. The gradation of the soil used in the design of a soil-cement mixture, should be representative of the gradation that is to be used in the field. If the gradation of the material in the field varies, the need for adjusting the cement content should be ascertained.

CHAPTER 6

CONSTRUCTION PHASE

Mixing

Central, continuous mixing plants were used in all projects since all the soil was taken from borrow pits. The soil, cement, and water, were fed simultaneously into a pugmill and were mixed for approximately fifteen seconds. The soil was carried from the stockpile to the pugmill, on a conveyor belt. The cement was fed onto this same belt. The quantity of cement added, was controlled by varying the rate of feed, until the required cement content by weight, was obtained. The rates of feed were then held constant. Thus, in effect the soil and cement were proportioned on a volumetric basis. Therefore any change in the dry unit weight of the soil would alter the cement content by weight. On this basis, the dry unit weight of the soil would have to vary approximately ten percent, to change the cement content by one percent.

The soil and cement were mixed at a water content as close to optimum (Standard Proctor) as possible. The water that was added was controlled by metering. The required rate of flow was determined by taking moisture content samples of the mixed material, and adjusting the flow until optimum moisture content was reached. The process was repeated several times each day. Close control over the moisture content was essential in compacting the soil-cement. Difficulty was encountered in compacting soil-cement at a moisture content above optimum. This caused

excessive rutting by the compacting equipment and resulted in a considerable delay in the time it normally took to compact the material.

The mixing cycle was adequate in so far as dispersing the cement uniformly through the soil was concerned. The problem was one of maintaining a constant cement content, for reasons mentioned previously.

Placement of the Material on the Roadway

The material was placed in one six inch lift[1] on the roadway by means of Jersey spreaders. The roadway was four spreader widths, and one half the roadway was paved at a time. Where only one spreader was available, approximately 500 feet of one lane was placed, the spreader was then moved back to bring the second lane up to the first. The placing of 500 feet took approximately twenty minutes. Where two spreaders were available, one-half the roadway was paved at a time, with the two spreaders working in tandem.

A specially adapted bituminous paver was tried, but it was found to be too slow. Its' advantages were that it maintained a mat of uniform thickness that conformed to the cross-section desired, and also provided initial compaction which eliminated the problem of initial breakdown of the material.

The only problem encountered in placement of the material, was segregation in the case of the Updike Lake sandstone. The material was end dumped in a conical-shaped pile, from the trucks into the spreader. The larger sized particles segre-

1 The specified compacted thickness of the lift.

gated, and the edges of the mat contained an excess of large size particles. This condition is illustrated by photo P-1 of Appendix III. The consequences of segregation were, low densities at the joints, and the possibility of considerable breakdown of sandstone at the joint, thus further weakening it.

Compaction

Various compaction techniques were used on the projects. Compaction equipment consisted of rubber-tire rollers, steel wheel rollers, vibrators and sheepsfoot rollers. The main problem of compaction was the initial breakdown of the material. The soil-cement as deposited by the Jersey spreaders was in a loose state. For this reason, it was difficult to make the initial pass without causing excessive rutting. On one project, the initial pass was made with a relatively light rubber-tire roller, and a heavier rubber-tire roller was used for the balance of the compaction. On the second project, a light rubber-tire roller was tried for the initial pass but it bogged down constantly and so its use had to be discontinued. The initial pass was then made by a heavy (50 ton) rubber-tire roller. Although no difficulty was encountered in making the first pass, the roller caused considerable rutting, with the result that compaction planes were left in the material at a depth of about two inches. On the third project, a Jackson vibrator was used to make the initial pass and final compaction was achieved by a rubber-tire roller.

The sheepsfoot roller was used for the sandstone material when it was found that adequate compaction could not be

attained using rubber-tire rollers alone.

The steel wheel roller was used sparingly, since it caused a wavy surface when used in relatively loose material, due to the pushing effect. It was often used in the final phase of compaction to remove any small surface irregularities. Another problem encountered with the steel wheel roller, was the continual "pick-up" of material by the wheels.

Thus the problem of compaction was primarily that of initial breakdown of the material. This was particularly true when the moisture content was well above optimum.

Surface Finishing

Following compaction, the base course surface was reshaped to remove irregularities, and to make the base course conform to the required cross section, Initially, this was done by one pass with a patrol blade which removed the excess material and placed it in a windrow along the roadway edge. The windrowed material was then bladed back across the roadway and recompacted. Blading the material over to the roadway edge, left a smooth plane. The material which was bladed back and recompacted, did not bind with the underlying course. Thus there was a thin lift of soil-cement, which varied in thickness from zero to approximately an inch, that did not adhere to the underlying course. This lift broke away readily under traffic, leaving a very irregular surface. This condition is illustrated by Photo P-2 of Appendix III. The entire thin lift was not removed prior to placing the bituminous surface course. The danger of this condition is that the thin layer may break up under traffic, leaving a cushion of loose material between the

soil-cement base course and the bitiminous surface course.

The finishing technique was later changed to the following. After the material was windrowed to the edge, the smooth plane was removed by scarifying the bladed surface, to a depth of approximately one-half inch. The windrowed material was then bladed back across the roadway and recompacted. This method provided a good bond between the two layers. A comparison of the results of the two methods is illustrated by photo P-3 of Appendix III.

The surface finishing was completed within two hours of the time the material was mixed at the plant.

Joints

(a) Longitudinal

As mentioned previously, two lanes of soil-cement were carried along together. Where two spreaders were used in tandem the longitudinal joint between the two lanes was thus eliminated. Where only one spreader was used, the lanes were compacted individually. Initially the first lane was compacted to the edges. This caused a lateral displacement of the material at the longitudinal joint, and as a result the thickness at the joint was somewhat less than six inches. The next lane when placed, overlapped the first lane at the joint, and was compacted in this way. Thus there was a compaction place at the joint and the material placed over the compaction plane varied in thickness from zero to approximately two inches. Because of the compaction plane there was no bond between the two layers and the top layer broke away

readily under traffic, leaving a very irregular joint. This condition is illustrated by photo P-4 of Appendix III. Here again, not all of the thin overlying layer was broken away and was covered by the bituminous surface material. This left a joint with a weak bond between the surfacing material and the underlying base. A similar condition existed at the centre longitudinal joint. The condition was later corrected by not compacting the first lane to the very edge, and compacting the joint after the second lane had been placed. Similarly, the centre joint was not compacted to the very edge and the non-compacted material was removed by either a blade or cutting disc prior to the placing of the adjacent lane.

(b) Transverse Joint

Transverse joints were used at the end of a days run or when construction was interrupted. They were also used where only one spreader was used, since there was a continual shifting from one lane to the other. Here again the matching of the joints was done in some instances, in a manner such that there were compaction planes with overlying material, at the joint. This overlying material broke away readily as illustrated by photo P-5 of Appendix III. The condition was later corrected by not compacting to the very edges and the joint was compacted after the paving of the lane had been resumed. A method used on another project was to place a six inch by six inch timber at the transverse joint and compact to the edge. When paving of the lane was to be resumed, the timber was removed leaving a square joint. This method was found to work satisfactorily.

Curing

Following final compaction, the roadway was kept moist by watering until a curing compound (Rapid Curing bituminous material) could be sprayed over the roadway surface. This method was found to be satisfactory, providing the surface could be kept moist until the curing compound was applied. On extremely hot days this became a problem due to the rate of evaporation, and in many instances the surface dried out before sufficient hydration took place. This resulted in a very thin layer of loose sand at the surface. Unless this layer of loose sand was removed prior to paving, it could cause slippage between the bituminous surface material and the base course.

It was found that a very light application of curing compound (approximately 1/10 gal/sq.yd.) gave the best results. Heavier applications caused considerable pick-up under traffic, leaving the surface exposed.

CONCLUSIONS-CONSTRUCTION METHODS

1. The method by which the soil-cement was mixed, was adequate in dispersing the cement uniformly through the soil, but did not provide a consistent cement content from time to time. Generally, the variations in cement content were greater than the four percent allowed for in the specifications. The method of controlling the moisture content was satisfactory providing a sufficient number of moisture content samples were taken and the flow was adjusted accordingly.
2. Optimum moisture content, or slightly below optimum, provided the best conditions for compacting the soil-cement. Moisture contents greater than optimum led to excessive rutting by the compacting equipment and a considerable increase in the length of time normally required to compact the material.
3. Jersey spreaders provided a fast and efficient method of placing the soil-cement on the roadway. Two spreaders working in tandem, gave the best results because of the elimination of one longitudinal joint, and numerous transverse joints. One disadvantage of the Jersey spreader was the segregation that took place in material containing aggregate-sized particles (sandstone), as the material was dumped into the spreader.
4. Rubber-tire rollers provided the best means of compacting the sandy soil-cement. The method was not satisfactory in compacting the soil-cement made from sandstone. In this

case large voids were left at the bottom of the base course after the material had been compacted. In the author's opinion, the first pass should have been made with vibratory compacting equipment. This would set up relative movement between the soil particles and would bring about a better rearrangement of the particles. The balance of the compaction could have been obtained by using heavy rubber tire rollers.

Steel rollers could only be used in the final phase of compaction. When used in relatively loose material they left a wavy surface. "Pick up" by the wheels was also a problem encountered, in using a steel wheel roller.

5. Any compaction planes near the surface of the soil-cement should be removed. Two layers separated by a compaction plane, do not bind and if the top layer is relatively thin, it breaks up under traffic.
6. Construction joints should be "squared off" prior to placing additional material. This applies to longitudinal and transverse construction joints. This is to avoid any over-lapping of material at the joint.
7. The surface of the soil-cement should not be allowed to dry out while hydration is taking place. The curing compound should be applied as soon after the material has been compacted, as possible. Keeping the surface moist by watering is not satisfactory in hot weather due to the rapid rate of evaporation.

RECOMMENDATIONS FOR FURTHER INVESTIGATION

On the basis of the results of the investigation, it is recommended:

1. That a further investigation be made of the relationship between the coefficient of uniformity of sandy soils, and the density-strength relationship of the soil-cement. The feasibility of using any such relationship in the design and control of soil-cement should be ascertained. A comprehensive investigation would be required, covering a wide range of gradation and cement content.
2. That for any investigation of soil-cement involving sandstone, a compactive method other than one utilizing impact be used. Impact causes a breakdown of the sandstone, which affects the results. This condition is not generally encountered in the field, and thus any correlation between field and laboratory values may be rendered inconsistent, on the basis of incompatability of compaction techniques alone.
3. That in any laboratory work involving the design of soil-cement, the method in which the material is to be taken from the borrow pit during construction, be used as a guide as to how the soil-cement should be prepared (re-gradation) in the laboratory. This may call for several designs if the material is to be removed sectionally from the borrow pit.
4. That greater emphasis be placed on cement content determination in the field for the purpose of evaluating the

material produced. The possibility of using a more expedient method of determining the cement content, should be investigated.

5. That the sections of the base course which exhibited low compressive strengths and high soil-cement losses, be inspected closely in the future to determine whether or not the soil-cement can withstand the expansion and shrinkage forces induced by the weathering agents. This would require periodical testing with time and a comparative assessment of the soil-cement's ability to retain its' load carrying capacity.

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APPENDIX I

SHORT-CUT TEST PROCEDURES FOR SANDY SOILS

The following short-cut test procedures for sandy soils were developed as a result of a correlation made by the Portland Cement Association of the test data obtained from testing 2,229 sandy soils.* These procedures do not involve new tests or additional equipment. Instead, data and charts developed from previous tests of similar soils are utilized to eliminate the need for some tests and greatly reduce the amount of work required. The only laboratory tests required are a grain-size analysis, moisture-density test and compressive-strength tests. Relatively small soil samples are needed and all tests, except the 7-day compressive-strength tests, can be completed in one day.

The procedures are applicable only to soils containing less than 50 per cent silt and clay-size material smaller than 0.05 mm., and less than 20 per cent clay-size material smaller than 0.005 mm. Dark grey to black soils—which obviously contain appreciable organic impurities and miscellaneous granular materials, such as cinders, caliche, chat, chert, marl, red dog, scoria, shale, slag, etc.—should be tested using the full procedures as described in Chapter 3 until information on local materials of these types is sufficient to permit use of short-cut procedures.

Although this procedure does not always indicate the minimum cement factor that can be used, it provides a safe cement factor generally close to that indicated by wet-dry and freeze-thaw tests. The procedure is being widely applied by engineers and builders and may largely replace the standard tests when experience in its use is gained and the relationships are checked. Possibly the charts and procedures may be modified to conform to local conditions if necessary.

When originally prepared, the charts for the short-cut procedure were based on cement contents calculated on a volume basis. In the following discussion the accompanying charts show cement contents by weight of soil. The maximum densities shown were obtained by using the minus No. 4 fraction of the soil..

Charts are being developed that are based on the maximum density obtained by tests using the total mixture instead of the minus No. 4 fraction.**

The nomenclature of textural classification used in this chapter has been revised to conform with the revised system now used by the U.S. Department of Agriculture.

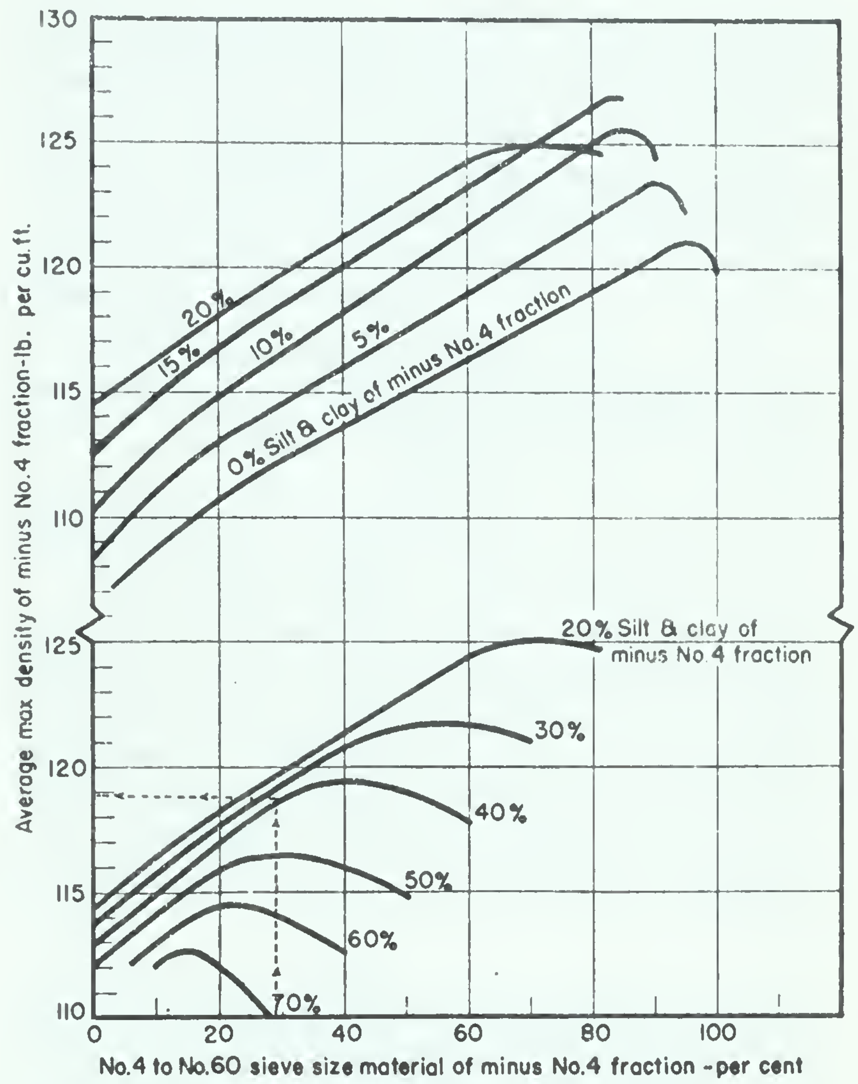

Fig. 37. Average maximum densities of the minus No. 4 fraction of soil-cement mixtures.

Step-By-Step Procedures

Short-cut test procedures involve

- determining the texture of the soil to permit its placement in either Group I or Group II,
- running a moisture-density test on a mixture of portland cement and the minus No. 4 fraction of the soil,
- determining the indicated portland cement requirement by the use of charts,

*See footnote, page 9.

**These charts should be completed soon and will be available free only in the United States and Canada from Portland Cement Association.

- verifying the indicated cement requirement by compressive-strength tests.

An example of the use of the procedure is also given.

Preliminary Steps

1. Make a grain-size analysis of the soil.
2. If the soil contains less than 20 per cent material smaller than 0.005 mm. and less than 50 per cent smaller than 0.05 mm., the short-cut procedure can be used, and the soil is placed in either Group I or Group II, as follows:

Group I

1. Less than 20 per cent smaller than 0.05 mm. and less than 25 per cent gravel larger than No. 10 sieve, or
2. 20 to 50 per cent smaller than 0.05 mm.

Group II

1. Less than 20 per cent smaller than 0.05 mm. and more than 25 per cent gravel larger than No. 10 sieve.

The short-cut tests do not apply to dark grey to black organic soils or to those soils containing more than 20 per cent 0.005 mm. clay-size material or more than 50 per cent silt and clay combined (smaller than 0.05 mm.). These soils should be tested using the modified testing procedures described in Chapter 3.

Group I Soils

Step 1:

Determine by test the maximum density and optimum moisture content for a mixture of the minus No. 4 fraction of the soil and portland cement. The cement content by weight to use can be obtained from Fig. 39 by using the combined silt and clay content of the minus No. 4 fraction of the soil* and an estimated density obtained from Fig. 37.

Step 2:

Using the maximum density obtained by test in Step 1, determine from Fig. 39 the indicated cement factor by weight of the minus No. 4 fraction of the soil.

Step 3:

A. Mold compressive-strength specimens** in triplicate at maximum density and optimum moisture using minus No. 4 soil and the cement factor obtained in Step 2.

B. Determine the average compressive strength of the specimens after 7 days of moist-room curing.

Step 4:

A. On Fig. 38, plot the average compressive-strength value obtained in Step 3B. If this value falls above the curve shown, the indicated cement factor by weight of the minus No. 4 fraction of the soil obtained in Step 2 is adequate. If the original soil sample contained material retained on the No. 4 sieve, it is necessary to convert this cement factor based on the minus No. 4 soil to the cement factor based on the total soil.

This is quickly done as follows: cement content by weight of total soil = cement content by weight of minus No. 4 soil $\times \dfrac{(100 - \text{per cent plus No. 4})}{100}$. This cement content by weight is then converted to a volume basis for field construction by using Fig. 40.

B. If the average strength value falls below the curve of Fig. 38, the indicated cement factor obtained in Step 2 is probably too low. Additional testing is needed to establish the cement requirement for the soil. These tests involve the determination of the maximum density of the total soil-cement mixture and molding and testing freeze-thaw specimens as described in Chapter 3. Generally, two freeze-thaw specimens will be adequate—one at the cement content by

*The percentage of combined silt and clay is usually given in relation to the total soil mixture for identification and classification purposes. If the soil contains material retained on the No. 4 sieve, it is necessary to convert this figure to the per cent based on the minus No. 4 fraction. Likewise, this is true of the amount of material between the No. 4 and No. 60 sieves. The conversions may be made using the following formulas:

Per cent (No. 4 to No. 60 sieve size) of minus No. 4 fraction

$$= \frac{\text{per cent (No. 4 to No. 60 sieve size) of total}}{100 - \text{per cent plus No. 4}} \times 100.$$

Per cent (silt + clay) of minus No. 4 fraction

$$= \frac{\text{per cent (silt + clay) of total}}{100 - \text{per cent plus No. 4}} \times 100.$$

**Two-inch diameter by 2-in. high specimens or 4-in. diameter by 4.6-in. high specimens may be molded using minus No. 4 soil-cement material. The 2-in. specimens shall be submerged in water for 1 hour before testing and the 4-in. specimens for 4 hours.

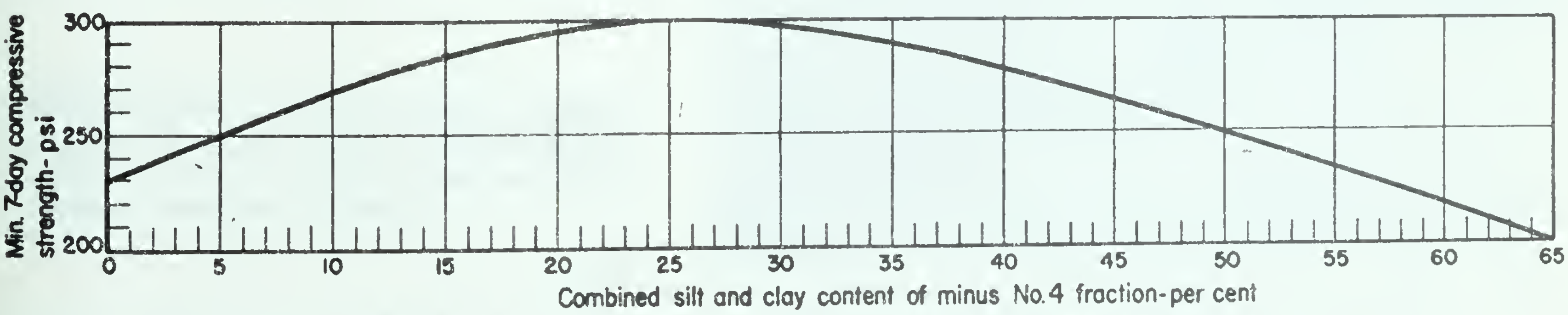

Fig. 38. Minimum 7-day compressive strengths required for Group I soils at the indicated cement content obtained from Fig. 39.

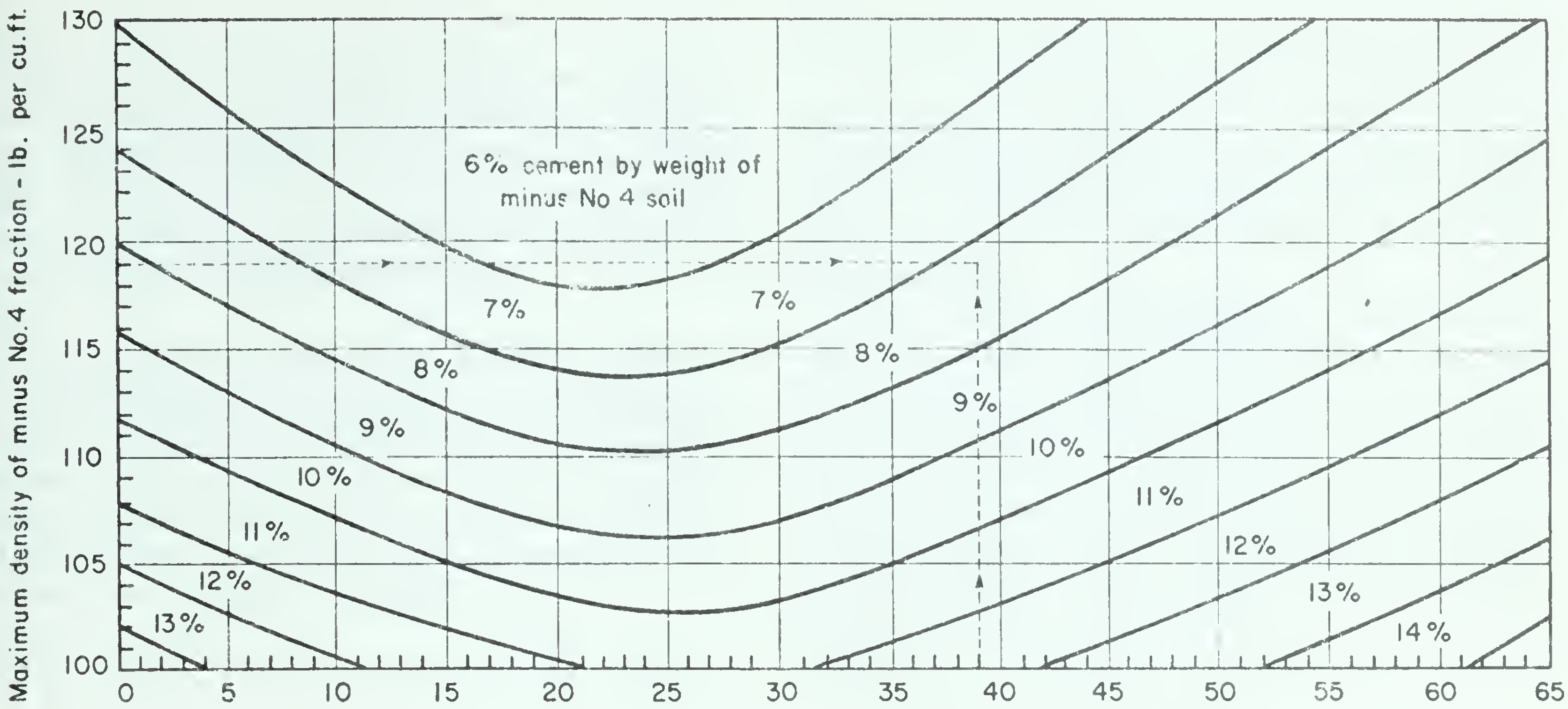

Fig. 39. Indicated cement content by weight of minus No. 4 fraction of Group I soils.

weight indicated as adequate in Step 4A based on the total soil, and one at a cement content two percentage points higher.

Group II Soils

Seven per cent cement by volume, based on the total mixture, is automatically the indicated cement factor for these soils for soil-cement construction.*

*Seven per cent portland cement by volume was the minimum cement factor recommended for these soils. It is quite probable that tests would have shown adequate hardening in some cases with less than 7 per cent cement. In past years the recommendation of a minimum of 7 per cent cement was considered necessary to insure quality construction. More recently considerable soil-cement has been satisfactorily constructed with cement factors well below 7 per cent. Modern construction equipment plus job know-how has made quality construction easier.

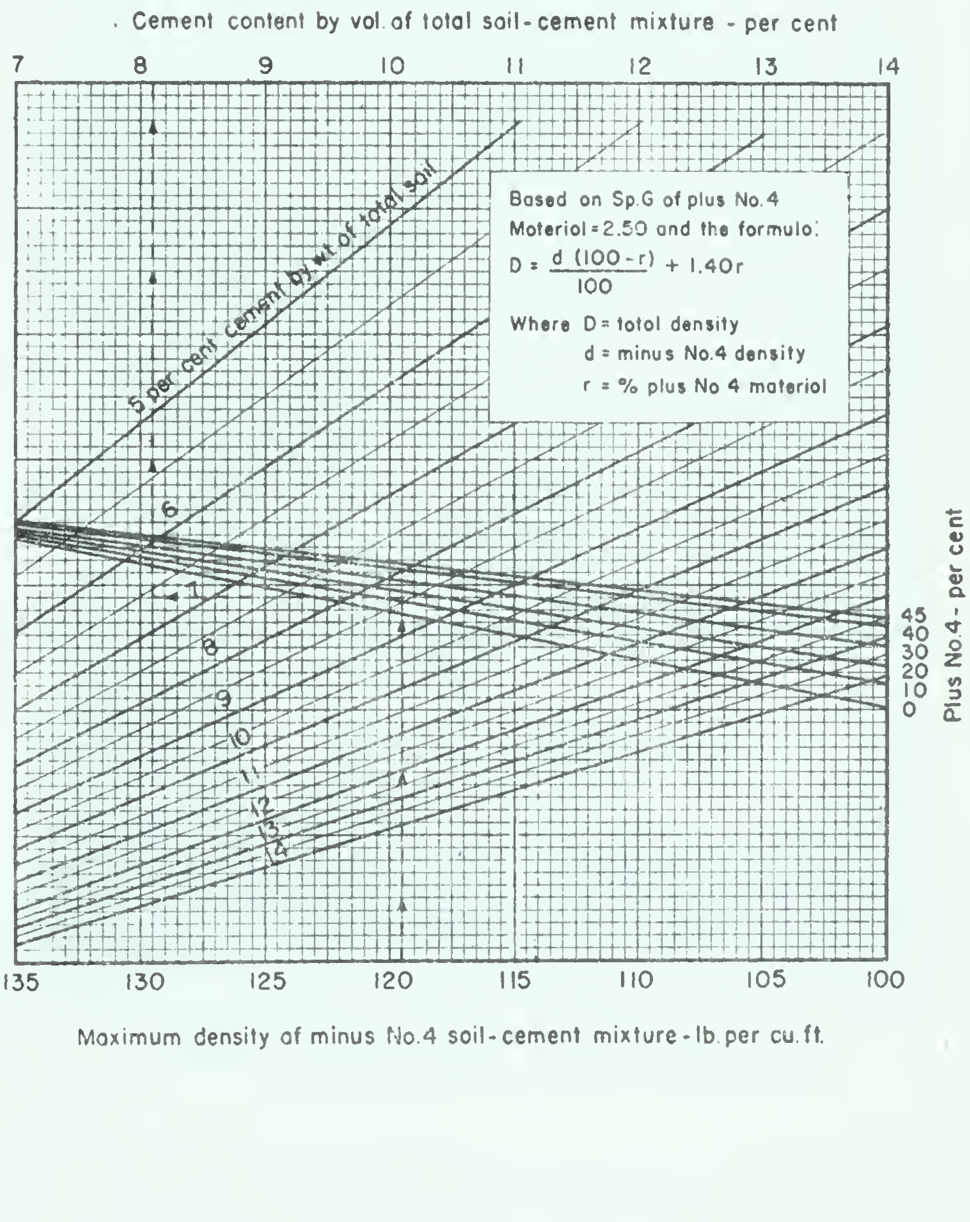

Fig. 40. Relation of cement content by weight of total soil to cement content by volume of total compacted soil-cement mixture (based on maximum density of minus No. 4 fraction).

Step 1:

Determine by test the maximum density and optimum moisture content for a mixture of the minus No. 4 fraction of the soil and portland cement. The cement content by weight of minus No. 4 soil to be used in the test can be determined from Fig. 41 by using the percentage of plus No. 4 material in the original soil sample.

Step 2:

A. Mold compressive-strength specimens* in triplicate at maximum density and optimum moisture using the minus No. 4 fraction of the soil and the cement content obtained from Fig. 42 by using the maximum density obtained in Step 1 and the percentage of plus No. 4 material

B. Determine the average compressive strength of the specimens after moist-room curing for 7 days.

Step 3:

A. On Fig. 43 plot the average compressive-strength value obtained in Step 2B. If this value falls above the line shown, 7 per cent cement by volume of the total soil-cement mixture is adequate for soil-cement construction. If the point falls well above the line, it is likely that less than 7 per cent cement would be satisfactory. This could be checked by conducting modified standard tests at lower cement contents.

B. If the average strength falls below the line of Fig. 43, 7 per cent cement by volume of the total mixture is probably not adequate. Additional testing is needed to establish the cement requirement for the soil. These tests involve the determination of the maximum density of the total soil-cement mixture and molding and testing freeze-thaw specimens as described in Chapter 3. Generally, two freeze-thaw specimens will be adequate, one at 5 per cent cement by weight of total soil and one at 7 per cent.

*See the second footnote, page 39.

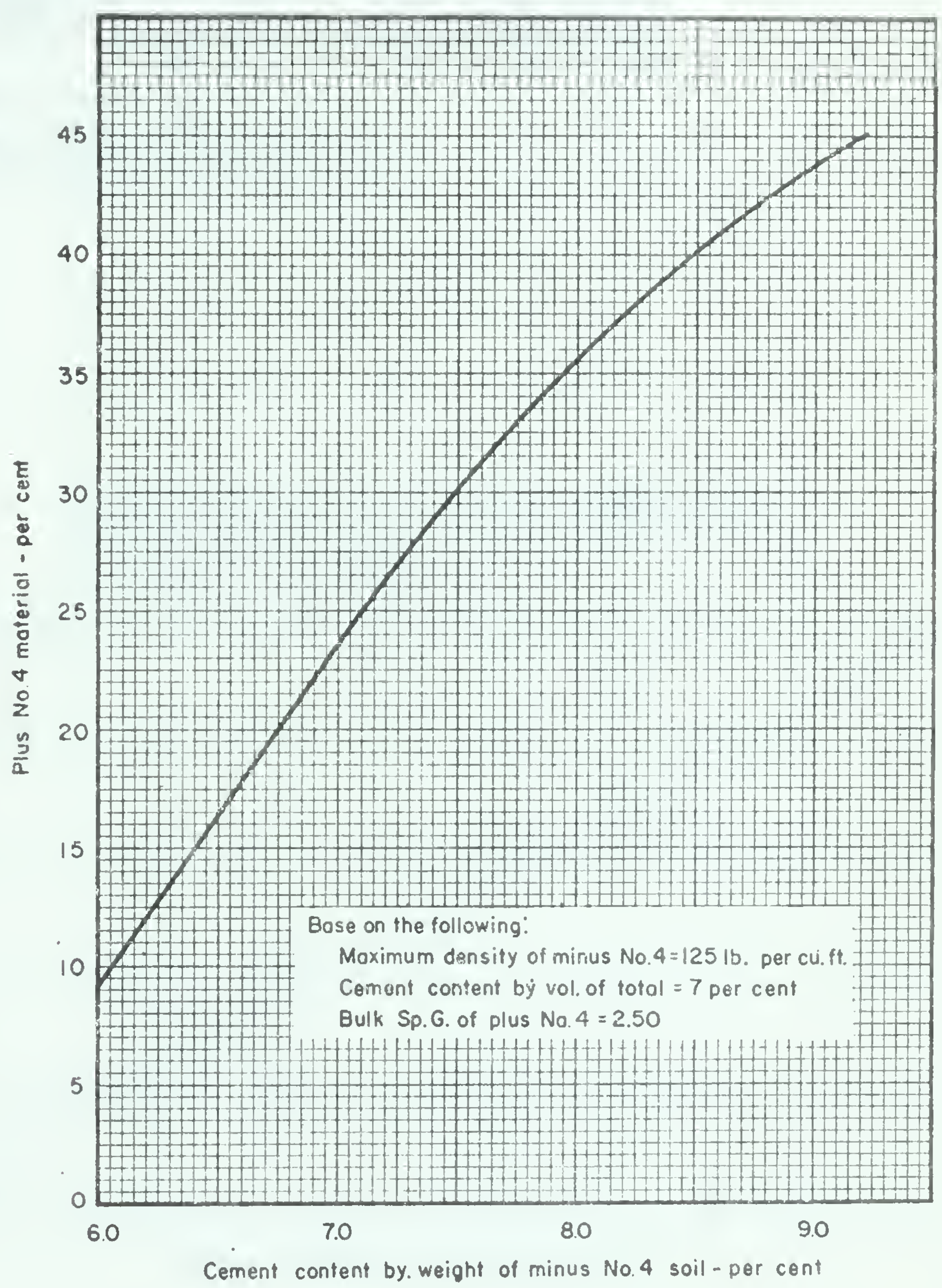

Fig. 41. Cement content by weight of minus No. 4 soil for moisture-density test of Group II soils.

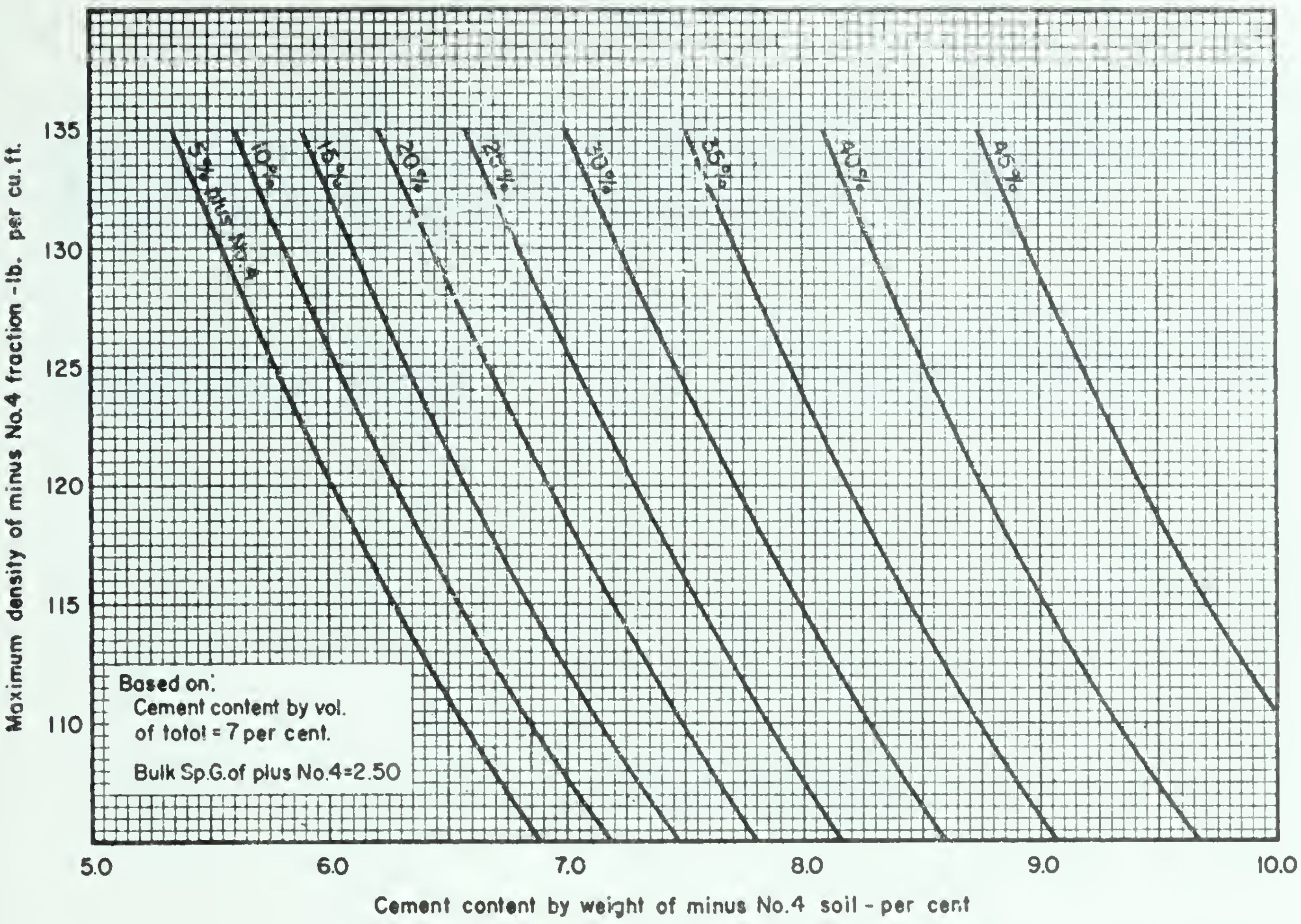

Fig. 42. Cement content by weight of minus No. 4 soil for compressive-strength specimens of Group II soils.

Fig. 43. Minimum 7-day compressive strengths required for Group II soils at cement contents equivalent to 7 per cent by volume of total mixture.

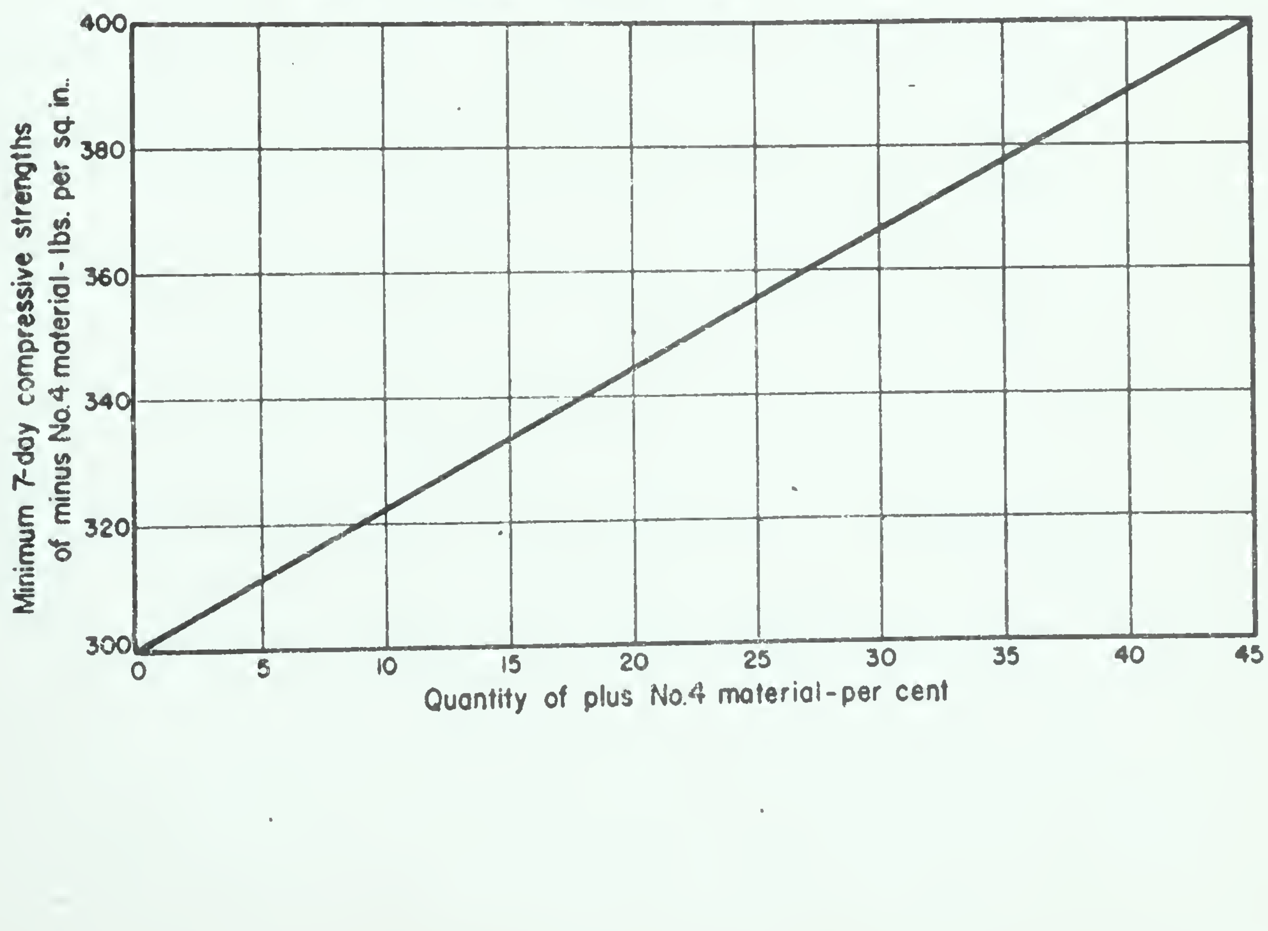

TABLE 1

ALLOWABLE SOIL-CEMENT LOSSES DURING 12 CYCLES OF EITHER WET-DRY OR FREEZE-THAW TEST IN ORDER THAT THE SOIL-CEMENT WITHSTAND THE FORCES OF SHRINKAGE AND EXPANSION.

AASHO Soil Groups	Maximum Allowable Soil-Cement Loss
A - 1 A - 2 - 4 A - 2 - 5 A - 3	14 percent
A - 2 - 6 A - 2 - 7 A - 4 A - 5	10 percent
A - 6 A - 7	7 percent

TABLE 2

CEMENT REQUIREMENTS OF AASHO SOIL GROUPS

AASHO Soil Group	Usual Range In Cement Requirement % by Vol.	Usual Range In Cement Requirement % by wt.	Estimated Cement Content % by Wt.	Cement Content For F-T Tests % by Wt.
A-1-a	5 to 7	3 to 5	5	3-5-7
A-1-b	7 to 9	3 to 8	6	4-6-8
A-2	7 to 10	5 to 9	7	5-7-9
A-3	8 to 12	7 to 11	9	7-9-11
A-4	8 to 12	7 to 12	10	8-10-12
A-5	8 to 12	8 to 13	10	8-10-12
A-6	10 to 14	9 to 15	12	10-12-14
A-7	10 to 14	10 to 16	13	11-13-15

TABLE 2a

AASHO CLASSIFICATION OF SOILS AND SOIL-AGGREGATE MIXTURES (WITH SUGGESTED SUBGROUPS)

General classification	Granular materials (35 percent or less passing No.200)							Silt-clay materials (more than 35 % passing No.200)			
Group classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7-5
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-6
Sieve analysis:											
Percent passing No. 10	50 max.	----	----	----	----	----	----	----	----	----	----
No. 40	30 max.	50 max.	51 min.	----	----	----	----	----	----	----	----
No.200	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.
Charact. of frac. passing No.40:											
Liquid limit	---		---	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.		NP	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.

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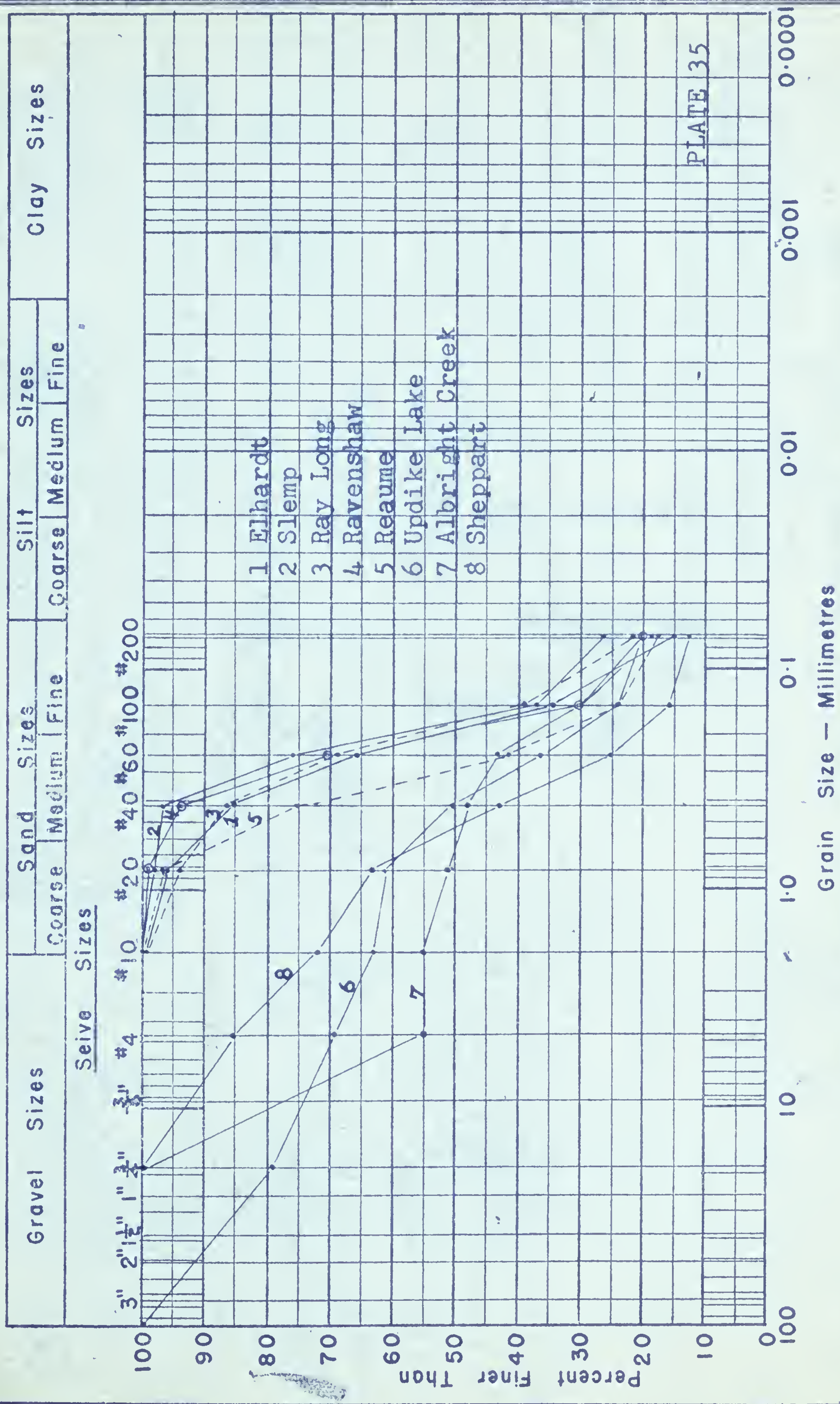
SOIL MECHANICS LABORATORY

GRAIN SIZE CURVE

PROJECT	
SITE	
SAMPLE	
LOCATION	
HOLE	DEPTH
TECHNICIAN	DATE



D_{10} = ____ mm.
D_{60} = ____ mm.
C_u ____

Remarks: Grain size distribution curves of the sands and sandstones used in the design of the various soil-cement mixtures.

Note: M.I.T. Grain Size Scale

SUMMARY OF DESIGN TESTS ON SOIL-CEMENT MIXTURES

Project: 12-B-1 and 2 Elhardt Pit

GRADATION

Sieve size	% passing
3/4 in.	100
No. 4	100
No. 10	99
No. 20	96
No. 40	85
No. 60	66
No. 100	34
No. 200	15

% smaller than 0.05 mm - 10

Soil Classification: A-2-4

Group: 1

COMPRESSIVE STRENGTH (psi)

Cement content (% by wt)	Age when tested (days)		
	seven	twenty eight	12 freeze thaw cycles
5	199	348	159
7	330	530	298
9	410	640	438

Laboratory optimum moisture content - 10.6%

Laboratory maximum density - 117.0 lbs/cu.ft.

Recommended cement content (% by weight)

1. Short-cut test procedure - 7%
2. Department of Highways - 8%
3. Portland Cement Association - 5.7%

SUMMARY OF DESIGN TESTS ON SOIL-CEMENT MIXTURES

Project: 12-B-1 and 2 Slemp Pit

GRADATION

Sieve size	% passing
3/4 in.	100
No. 4	100
No. 10	100
No. 20	98
No. 40	97
No. 60	76
No. 100	37
No. 200	27

% smaller than 0.05 mm - 20

Soil Classification: A-2-4

Group: 1

COMPRESSIVE STRENGTH (psi)

Cement content (% by wt)	Age when tested (days)		
	seven	twenty eight	12 freeze thaw cycles
5	182	---	132
7	232	---	260
9	330	---	410

Laboratory optimum moisture content - 13.6%

Laboratory maximum density - 113.8 lbs/cu.ft.

Recommended cement content (% by weight)

1. Short-cut test procedure - 8%
2. Department of Highways - 10%
3. Portland Cement Association - 8.8%

SUMMARY OF DESIGN TESTS ON SOIL-CEMENT MIXTURES

Project: 12-B-1 and 2 Ray Long Pit

GRADATION

Sieve size	% passing
3/4 in.	100
No. 4	100
No. 10	98
No. 20	94
No. 40	86
No. 60	68
No. 100	38
No. 200	22

% smaller than 0.05 mm - 10

Soil Classification: A-2-4

Group: 1

COMPRESSIVE STRENGTH (psi)

Cement content (% by wt)	Age when tested (days)		
	seven	twenty eight	12 freeze thaw cycles
5	234	328	---
7	320	478	243
9	401	573	414

Laboratory optimum moisture content - 12.8%

Laboratory maximum density - 116.0 lbs/cu.ft.

Recommended cement content (% by weight)

1. Short-cut test procedure - 8%
2. Department of Highways - 8%
3. Portland Cement Association - 8.1%

SUMMARY OF DESIGN TESTS ON SOIL-CEMENT MIXTURES

Project: 12-B-1 and 2 Ravenshaw Pit

GRADATION

Sieve size	% passing
3/4 in.	100
No. 4	100
No. 10	100
No. 20	98
No. 40	94
No. 60	70
No. 100	30
No. 200	20

% smaller than .05 mm - 17

Soil Classification: A-2-4

Group: 1

COMPRESSIVE STRENGTH (psi)

Cement content (% by wt)	Age when tested (days)		
	seven	twenty eight	12 freeze thaw cycles
5	243	302	46
7	294	418	148
9	294	570	304

Laboratory optimum moisture content - 13.6%

Laboratory maximum density - 113.0 lbs/cu.ft.

Recommended cement content (% by weight)

1. Short-cut test procedure - 7%
2. Department of Highways - 9%
3. Portland Cement Association - 7.4%

SUMMARY OF DESIGN TESTS ON SOIL-CEMENT MIXTURES

Project: 2-K-2 Reaume Pit

GRADATION

Sieve size	% passing
3/4 in.	100
No. 4	100
No. 10	99
No. 20	97
No. 40	75
No. 60	42
No. 100	24
No. 200	17

% smaller than 0.05 mm - 15

Soil Classification: A-2-4

Group: 1

COMPRESSIVE STRENGTH (psi)

Cement content (% by wt)	Age when tested (days)		
	seven	twenty eight	12 freeze thaw cycles
7	228	304	167
9	310	407	254
11	423	535	396

Laboratory optimum moisture content - 14.4%

Laboratory maximum density - 109.0 lbs/cu.ft.

Recommended cement content (% by weight)

1. Short-cut test procedure - 9%
2. Department of Highways - 10%
3. Portland Cement Association - 9.3%

SUMMARY OF DESIGN TESTS ON SOIL-CEMENT MIXTURES

Project: 2-K-2 Updike Lake Pit

GRADATION

Sieve Size	% passing
3 - in.	100
3/4 in.	79
No. 4	69
No. 10	63
No. 20	62
No. 40	50
No. 60	37
No. 100	24
No. 200	20

% smaller than 0.05 mm - 18

Soil Classification: A-1-b

Group: 11

COMPRESSIVE STRENGTH (psi)

Cement content (% by wt)	Age when tested (days)		
	seven	twenty eight	12 freeze thaw cycles
4	302	435	---
6	428	623	---
8	556	822	540

Laboratory optimum moisture content - 14.0%

Laboratory maximum density - 115.4 lbs/cu.ft.

Recommended cement content (% by weight)

1. Short-cut test procedure - 6.2%
2. Department of Highways - 8%
3. Portland Cement Association - 6.8%

SUMMARY OF DESIGN TESTS ON SOIL-CEMENT MIXTURES

Project: 2-k-2 Albright Creek Pit

GRADATION

Sieve size	% passing
3 - in.	100
3/4 in.	100
No. 4	55
No. 10	55
No. 20	52
No. 40	48
No. 60	43
No. 100	30
No. 200	18

% smaller than 0.05 mm - 13

Soil Classification: A-1-b

Group: 11

COMPRESSIVE STRENGTH (psi)

Cement content (% by wt)	Age when tested (days)		
	seven	twenty eight	12 freeze thaw cycles
4	325	359	*
6	428	556	*
8	543	765	576

Laboratory optimum moisture content - 12.5%

Laboratory maximum density - 118.5 lbs/cu.ft.

Recommended cement content (% by weight)

1. Short-cut test procedure - 6%
2. Department of Highways - 8%
3. Portland Cement Association - 5.4%

* Specimens crumbled under freeze-thaw action

SUMMARY OF DESIGN TESTS ON SOIL-CEMENT MIXTURES

Project: 28-b-2 Sheppert Pit

GRADATION

Sieve size	% passing
3/4 in.	100
No. 4	85
No. 10	73
No. 20	63
No. 40	43
No. 60	25
No. 100	16
No. 200	13

% smaller than 0.05 mm - 10

Soil Classification: A-1-b

Group: 1

COMPRESSIVE STRENGTH (psi)

Cement content (% by wt)	Age when tested (days)		
	seven	twenty eight	12 freeze thaw cycles
4	333	408	306
6	608	868	725
8	1055	1370	1142

Laboratory optimum moisture content - 7.2%

Laboratory maximum density - 129.5 lbs/cu.ft.

Recommended cement content (% by weight)

1. Short-cut test procedure - 6%
2. Department of Highways - 6%

APPENDIX II

TEST DATA

LABORATORY INVESTIGATION

DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

ELHARDT PIT

Specimen No.	Compactive Effort (No.Blows)	Dry Density (lbs/cu.ft)	Compressive Str. (psi)	Average Strength	Average Density
D-E 1	5	107.0	118		
D-E 2	5	106.5	111	112	106.4
D-E 3	5	105.7	105		
D-E 4	15	112.5	166		
D-E 5	15	112.1	160	160	112.0
D-E 6	15	111.5	154		
D-E 7	25	115.8	200		
D-E 8	25	115.9	200	200	115.8
D-E 9	25	115.8	198		
D-E10	50	120.0	205		
D-E11	50	119.3	240	☆ 246	☆ 119.2
D-E12	50	119.0	248		

Cement Content - 5% Proctor Density - 117.0 Optimum Moisture - 10.6%

☆ Average of D-E11 and D-E12.

DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

ELHARDT PIT

Specimen No.	Compactive Effort (No.Blows)	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Strength	Average Density
D-E13	5	107.3	196		
D-E14	5	106.6	202	199	106.7
D-E15	5	106.2	199		
D-E16	15	114.2	261		
D-E17	15	113.6	269	267	113.6
D-E18	15	113.1	271		
D-E19	25	115.5	308		
D-E20	25	115.5	300	306	115.5
D-E21	25	115.6	309		
D-E22	50	120.5	309		
D-E23	50	119.7	309		
D-E24	50	119.5	354	☆ 354	☆ 119.5

Cement Content - 7%   Proctor Density - 117.0   Optimum Moisture - 10.6%

☆ D-E24.

DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

ELHARDT PIT

Specimen No.	Compactive Effort (No.Blows)	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Strength	Average Density
D-E25	5	107.2	261		
D-E26	5	107.3	266	260	107.2
D-E27	5	107.1	253		
D-E28	15	114.9	390		
D-E29	15	114.4	399	389	114.3
D-E30	15	113.6	379		
D-E31	25	117.4	473		
D-E32	25	117.3	466	472	117.2
D-E33	25	116.9	475		
D-E34	50	119.8	538		
D-E35	50	119.7	535	539	119.6
D-E36	50	119.2	543		

Cement Content - 9%   Proctor Density - 117.0   Optimum Moisture - 10.6%

DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

SLEMP PIT

Specimen No.	Compactive Effort (No.Blows)	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Strength	Average Density
D-S 1	5	94.4	120	119	94.0
D-S 2	5	93.9	120		
D-S 3	5	93.8	117		
D-S 4	15	100.4	178		
D-S 5	15	100.7	168	170	100.5
D-S 6	15	100.4	163		
D-S 7	25	103.4	204		
D-S 8	25	103.5	199	199	103.4
D-S 9	25	103.4	195		
D-S10	50	107.9	274		
D-S11	50	107.5	259	269	107.7
D-S12	50	107.7	275		

Cement Content - 7% Proctor Density - 106.6 Optimum Moisture - 14.0%

DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

SLEMP PIT

Specimen No.	Compactive Effort (No.Blows)	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Strength	Average Density
D-S13	5	95.7	198		
D-S14	5	95.0	192	192	95.3
D-S15	5	95.2			
D-S16	15	102.6	276		
D-S17	15	102.3	284	276	102.2
D-S18	15	101.7	268		
D-S19	25	105.3	330		
D-S20	25	105.3	317	320	105.2
D-S21	25	104.9	312		
D-S22	50	110.0	396		
D-S23	50	109.2	373	381	109.4
D-S24	50	109.0	373		

Cement Content - 9% Proctor Density - 106.6 Optimum Moisture - 14.0%

DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

SLEMP PIT

Specimen No.	Compactive Effort (No.Blows)	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Strength	Average Density
D-S25	5	96.1	247		
D-S26	5	96.4	251	250	96.0
D-S27	5	95.6	252		
D-S28	15	103.5	358		
D-S29	15	103.6	362	356	103.3
D-S30	15	102.9	349		
D-S31	25	106.5	400		
D-S32	25	106.6	394	410	106.6
D-S33	25	106.9	435		
D-S34	50	110.5	505		
D-S35	50	110.7	502	502	110.6
D-S36	50	110.6	500		

Cement Content - 11%　　Proctor Density - 106.6　　Optimum Moisture - 14.0%

DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

RAY LONG PIT

Specimen No.	Compactive Effort (No.Blows)	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Strength	Average Density
D-RL 1	5	102.6	128		
D-RL 2	5	101.9	128	133	102.1
D-RL 3	5	101.9	141		
D-RL 4	15	112.3	248		
D-RL 5	15	111.7	229	235	111.7
D-RL 6	15	111.7	228		
D-RL 7	25	114.5	260		
D-RL 8	25	114.8	273	260	114.2
D-RL 9	25	113.3	247		
D-RL10	50	117.4	281		
D-RL11	50	116.7	292	290	117.1
D-RL12	50	116.9	299		

Cement Content - 6%   Proctor Density - 116.0 lbs/cu.ft.   Optimum Moisture - 12.8%

DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

RAY LONG PIT

Specimen No.	Compactive Effort (No.Blows)	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Strength	Average Density
D-RL13	5	104.4	204		
D-RL14	5	103.9	200	202	103.8
D-RL15	5	103.3	206		
D-RL16	15	110.7	301		
D-RL17	15	111.3	307	305	111.1
D-RL18	15	111.4	304		
D-RL19	25	115.5	335		
D-RL20	25	115.1	343	338	114.8
D-RL21	25	114.6			
D-RL22	50	117.2	☆ 282		
D-RL23	50	117.3	☆ 363		
D-RL24	50	116.8	☆ 369		

Cement Content - 8%   Proctor Density - 116.0 lbs/cu.ft.   Optimum Moisture - 12.8%

☆ Values inconsistent with the rest and therefore were not used.

DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

RAY LONG PIT

Specimen No.	Compactive Effort (No.Blows)	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Strength	Average Density
D-RL25	5	105.8	290		
D-RL26	5	105.1	280	278	105.0
D-RL27	5	104.0	263		
D-RL28	15	112.9	383		
D-RL29	15	112.0	370	390	112.5
D-RL30	15	112.7	418		
D-RL31	25	114.9	402		
D-RL32	25	114.2	393	396	114.3
D-RL33	25	113.8	392		
D-RL34	50	117.3	455		
D-RL35	50	116.8	421	442	117.0
D-RL36	50	116.8	454		

Cement Content - 10% Proctor Density - 116.0 lbs/cu.ft. Optimum Moisture - 12.8%

DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

RAVENSHAW PIT

Specimen No.	Compactive Effort (No.Blows)	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Strength	Average Density
D-Ra 1	5	105.2	121		
D-Ra 2	5	103.7	108	114	103.7
D-Ra 3	5	102.2	112		
D-Ra 4	15	109.9	220		
D-Ra 5	15	108.2	201	201	108.3
D-Ra 6	15	107.1	175		
D-Ra 7	25	114.6	292		
D-Ra 8	25	113.0	281	281	113.1
D-Ra 9	25	112.3	270		
D-Ra10	50	118.0	359		
D-Ra11	50	116.6	355	344	116.7
D-Ra12	50	116.1	318		

Cement Content - 7%   Proctor Density - 115.0 lbs/cu.ft.   Optimum Moisture - 14.6%

DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

RAVENSHAW PIT

Specimen No.	Compactive Effort (No.Blows)	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Strength	Average Density
D-Ra13	5	107.6	203		
D-Ra14	5	108.8	244	223	108.1
D-Ra15	5	107.8			
D-Ra16	15	111.7	278		
D-Ra17	15	111.1	283	271	110.9
D-Ra18	15	110.5	252		
D-Ra19	25	116.4	404		
D-Ra20	25	116.0	402	377	115.5
D-Ra21	25	114.5	325		
D-Ra22	50	119.0	453		
D-Ra23	50	119.1	433	430	119.0
D-Ra24	50	119.0	402		

Cement Content - 9% Proctor Density - 115.0 lbs/cu.ft. Optimum Moisture - 14.6%

DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

RAVENSHAW PIT

Specimen No.	Compactive Effort (No. Blows)	Dry Density (lbs/cu.ft)	Compressive Str. (psi)	Average Strength	Average Density
D-Ra25	5	105.3	282		
D-Ra26	5	105.4	295	284	105.5
D-Ra27	5	105.8	275		
D-Ra28	15	110.0	408		
D-Ra29	15	110.0	390	374	109.5
D-Ra30	15	108.9	321		
D-Ra31	25	115.5	558		
D-Ra32	25	115.1	526	520	115.1
D-Ra33	25	114.8	477		
D-Ra34	50	120.0	563		
D-Ra35	50	119.6	580	569	119.4
D-Ra36	50	118.6	565		

Cement Content - 11% Proctor Density - 115.0 lbs/cu.ft. Optimum Moisture - 14.6%

DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

REAUME PIT

Specimen No.	Compactive Effort (No.Blows)	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Strength	Average Density
D-R 1	5	97.4	158		
D-R 2	5	97.5	132	* 124	* 97.4
D-R 3	5	97.2	116		
D-R 4	15	102.7	183		
D-R 5	15	102.2	169	176	102.6
D-R 6	15	103.0	176		
D-R 7	25	105.8	198		
D-R 8	25	105.6	203	204	105.8
D-R 9	25	105.8	210		
D-R10	50	108.6	230		
D-R11	50	108.4	219	247	108.7
D-R12	50	108.7	253		

Cement Content - 7%   Proctor Density - 109.0 lbs/cu.ft.   Optimum Moisture - 14.4%

* Average of D-R2 and D-R3

DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

REAUME PIT

Specimen No.	Compactive Effort (No.Blows)	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Strength	Average Density
D-R13	5	98.3	193		
D-R14	5	98.3	197	198	98.4
D-R15	5	98.6	204		
D-R16	15	103.8	316		
D-R17	15	103.6	286	292	103.6
D-R18	15	103.5	275		
D-R19	25	106.7	340		
D-R20	25	106.9	338	333	106.6
D-R21	25	106.3	320		
D-R22	50	110.8	399		
D-R23	50	110.9	400	400	110.8
D-R24	50	110.8	---		

Cement Content - 9%   Proctor Density - 109.0 lbs/cu.ft.   Optimum Moisture - 14.4%

DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

REAUME PIT

Specimen No.	Compactive Effort (No.Blows)	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Strength	Average Density
D-R25	5	102.3	298		
D-R26	5	101.9	285	292	102.0
D-R27	5	101.8	293		
D-R28	15	105.8	363		
D-R29	15	105.4	384	375	105.8
D-R30	15	106.3	378		
D-R31	25	110.8	438		
D-R32	25	110.2	442	440	110.6
D-R33	25	109.7	375		
D-R34	50	114.0	542		
D-R35	50	114.2	521	527	114.0
D-R36	50	113.9	518		

Cement Content - 11% Proctor Density - 109.0 lbs/cu.ft. Optimum Moisture - 14.4%

DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

UPDIKE LAKE PIT

Specimen No.	Compactive Effort (No.Blows)	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Strength	Average Density
D-U 1	5	100.5	55		
D-U 2	5	101.1	92	70	101.8
D-U 3	5	103.8	64		
D-U 4	15	106.0	116		
D-U 5	15	105.0	120	108	104.7
D-U 6	15	103.2	88		
D-U 7	25	109.0	181		
D-U 8	25	108.8	163	183	109.7
D-U 9	25	111.3	204		
D-U10	50	114.4	230		
D-U11	50	113.8	242	235	113.1
D-U12	50	111.0	232		

Cement Content - 8%   Proctor Density - 115.4 lbs/cu.ft.   Optimum Moisture - 14.0%

DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

UPDIKE LAKE PIT

Specimen No.	Compactive Effort (No.Blows)	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Strength	Average Density
D-U13	5	101.3	109		
D-U14	5	102.9	120	124	102.4
D-U15	5	104.1	144		
D-U16	15	104.4	134		
D-U17	15	105.0	119	* 140	* 105.1
D-U18	15	105.8	145		
D-U19	25	108.2	224		
D-U20	25	109.8	197	** 207	** 108.2
D-U21	25	108.2	190		
D-U22	50	112.6	306		
D-U23	50	111.0	254	*** 280	*** 111.8
D-U24	50	111.4	244		

Cement Content - 10%   Proctor Density - 115.4 lbs/cu.ft.   Optimum Moisture - 14.0%

* Average of D-U16 and D-U18

** Average of D-U19 and D-U21

*** Average of D-U22 and D-U23

DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

UPDIKE LAKE PIT

Specimen No.	Compactive Effort (No.Blows)	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Strength	Average Density
D-U25	5	104.5	214		
D-U26	5	103.8	197	179	103.3
D-U27	5	101.5	126		
D-U28	15	106.2	191		
D-U29	15	106.2	187	* 189	* 106.2
D-U30	15	104.0	178		
D-U31	25	111.2	366		
D-U32	25	111.1	344	** 355	** 111.2
D-U33	25	108.2	284		
D-U34	50	114.9	478		
D-U35	50	111.4	414	*** 446	*** 113.2
D-U36	50	109.9	280		

Cement Content - 12%   Proctor Density - 115.4 lbs/cu.ft.   Optimum Moisture - 14.0%

* Average of D-U28 and D-U29

** Average of D-U31 and D-U32

*** Average of D-U34 and D-U35

EFFECT OF ELAPSED TIME ON DENSITY AND COMPRESSIVE STRENGTH

SUMMARY SHEET

Specimen No.	Elapsed Time(hrs)	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Density	Average Strength
T-16	0	115.5	335		
T-17	0	115.1	343	* 115.3	* 339
T-18	0	114.6	366		
T-19	1	113.4	316		
T-20	1	112.6	314	112.8	305
T-21	1	112.2	286		
T-22	2	107.9	197		
T-23	2	108.0	214	107.9	208
T-24	2	107.7	214		
T-25	3	105.8	156		
T-26	3	105.6	158	105.4	151
T-27	3	104.8	8		
T-28	4	105.8	156		
T-29	4	105.6	158	105.4	
-30					

Note: all specimens were formed at standard proctor compactive effort

EFFECT OF ELAPSED TIME ON DENSITY AND COMPRESSIVE STRENGTH

SUMMARY SHEET

Specimen No.	Elapsed Time(hrs)	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Density	Average Strength
T-16	0	115.5	335		
T-17	0	115.1	343	☆ 115.3	☆ 339
T-18	0	114.6	366		
T-19	1	113.4	316		
T-20	1	112.6	314	112.8	305
T-21	1	112.2	286		
T-22	2	107.9	197		
T-23	2	108.0	214	107.9	208
T-24	2	107.7	214		
T-25	3	105.8	156		
T-26	3	105.6	158	105.4	151
T-27	3	104.8	138		
T-28	4	103.8	132		
T-29	4	104.3	136	103.8	131
T-30	4	103.3	126		

☆ Average of T-16 and 17 only

Note: All specimens were formed at Standard Proctor Compactive Effort

Ray Long material used

STRENGTH-DENSITY RELATIONSHIP VERSUS UNIFORMITY COEFFICIENT

SUMMARY SHEET

Cu = 3		Cu = 5		Cu = 8		Cu = 10	
Dry Density (lbs/cu.ft)	Comp. Str. (psi)	Dry Density (lbs/cu.ft)	Comp. Str. (psi)	Dry Density (lbs/cu.ft)	Comp. Str. (psi)	Dry Density (lbs/cu.ft)	Comp. Str. (psi)
102.8	282	108.2	235	108.9	131	108.9	158
103.1	296	109.9	337	109.5	315	112.4	246
107.1	414	111.0	282	109.9	410	112.6	228
107.5	332	111.3	346	110.8	315	115.2	244
109.3	443	113.0	495	115.0	436	115.2	215
112.0	504	114.8	394	116.0	540	116.9	364
112.0	525	115.0	467	116.2	527	117.4	452
113.7	605	116.0	490	116.2	574	118.5	384
114.1	502	116.5	382	117.8	644	121.1	545
115.2	588	117.3	487	118.9	550	122.9	532
116.8	668	117.5	556	120.7	888	122.9	428
118.3	438	119.2	843	121.5	770	124.2	640

Cement Content - 10 percent by weight

Strengths uncorrected for the l/d ratio

APPENDIX III

TEST DATA

FIELD INVESTIGATION

FIELD DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

RAVENSHAW PIT

PROCTOR SPECIMENS					CORES		
Specimen No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Density	Average Strength	Core No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)
Ra-61	97.8	69			RaC-62	115.1	310
Ra-62	96.8	53	96.7	64	RaC-64	111.2	198
Ra-63	95.6	53			RaC-66	113.5	308
Ra-64	103.7	87			RaC-68	114.5	274
Ra-65	102.3	98	102.3	96	RaC-70	114.2	262
Ra-66	102.3	93			RaC-72	114.0	232
Ra-67	111.1	145					
Ra-68	109.2	150	109.9	143			
Ra-69	109.3	134					
Ra-70	115.0	202					
Ra-71	114.3	208	114.3	194			
Ra-72	113.5	171					

LOCATION: Specimens - 1786+50 6' Lt. Cores - RaC - 62 to 66 1786+50 6' Lt.

DATE: September 2, 1959 - RaC - 68 to 72 1782+00 18' Lt.

FIELD DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

RAVENSHAW PIT

PROCTOR SPECIMENS					CORES		
Specimen No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Density	Average Strength	Core No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)
Ra-73	99.3	128			RaC-80	112.1	265
Ra-74	96.3	93	97.0	99	RaC-82	113.2	284
Ra-75	95.3	96			RaC-84	107.8	284
Ra-76	105.0	208					
Ra-77	103.1	155	102.6	164			
Ra-78	100.6	122					
Ra-79	112.4	322					
Ra-80	109.0	243	109.9	282			
Ra-81	106.4	---					
Ra-82	116.5	356					
Ra-83	113.3	322	114.6	337			
Ra-84	114.0	322					

LOCATION: Specimens - 1858+00 18' Lt. Cores - 1858+00 18' Lt.

DATE: September 4, 1959

FIELD DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

RAVENSHAW PIT

PROCTOR SPECIMENS					CORES		
Specimen No.	Dry Density (lbs/cu.ft)	Compressive Str. (psi)	Average Density	Average Strength	Core No.	Dry Density (lbs/cu.ft)	Compressive Str. (psi)
Ra-85	100.3	139			RaC-86	117.5	197
Ra-86	96.5	100	97.4	107	RaC-88	118.0	294
Ra-87	95.5	82			RaC-90	112.6	244
Ra-88	104.6	140			RaC-92	116.0	279
Ra-89	103.3	156	103.9	148	RaC-94	113.5	152
Ra-90	102.6	99			RaC-96	114.0	161
Ra-91	112.1	290					
Ra-92	110.0	226	109.3	220			
Ra-93	108.6	214					
Ra-94	116.1	300					
Ra-95	115.3	249	114.9	283			
Ra-96	113.8	266					

LOCATION: Specimens - 1882+25 18' Lt. Cores - RaC - 86 to 90 1882+25 18' Lt.

- RaC - 92 to 96 1885+00 18' Lt.

DATE: September 7, 1959

Cement Content - 12.4%

FIELD DENSITY-STRENGTH RELATIONSHIP - SUMMARY SHEET

RAVENSHAW PIT

PROCTOR SPECIMENS					CORES		
Specimen No.	Dry Density (lbs/cu.ft)	Compressive Str. (psi)	Average Density	Average Strength	Core No.	Dry Density (lbs/cu.ft)	Compressive Str. (psi)
Ra-109	96.6	116			RaC-110	105.0	306
Ra-110	94.8	93			RaC-112	108.1	284
Ra-111	93.9	76			RaC-114	109.1	267
Ra-112	102.6	166			RaC-116	112.0	278
Ra-113	100.0	139			RaC-118	109.9	203
Ra-114	98.3	105			RaC-120	112.6	266
Ra-115	109.8	248					
Ra-116	107.0	238					
Ra-117	105.9	191					
Ra-118	112.5	267					
Ra-119	111.3	284					
Ra-120	110.5	250					

LOCATION: Specimens - 1956+25 18' Lt. Cores - RaC-110 to 114 1956+25 18' Lt.
- RaC-116 to 120 1960+00 6' Lt.

DATE: September 15, 1959

Cement Content - 7.3%

Note: All points were plotted instead of averages because of wide scattering of points.

FIELD DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

RAVENSHAW PIT

PROCTOR SPECIMENS					CORES		
Specimen No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Density	Average Strength	Core No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)
Ra-151	98.3	87			RaC-160	106.0	266
Ra-152	93.0	64	94.8	68	RaC-162	106.8	208
Ra-153	93.2	53					
Ra-154	101.8	145					
Ra-155	99.0	88	100.3	116			
Ra-156	100.1	116					
Ra-157	108.1	214					
Ra-158	106.4	176	107.4	195			
Ra-159	107.4	195					
Ra-160	113.2	267					
Ra-161	113.2	270	113.1	266			
Ra-162	112.9	260					

LOCATION: Specimens - 1884+00 18' Rt. Cores - 1884+00 18' Rt.

DATE: September 21, 1959

Cement Content - 8.1%

FIELD DENSITY-STRENGTH RELATIONSHIP - SUMMARY SHEET

RAVENSHAW PIT

PROCTOR SPECIMENS					CORES		
Specimen No.	Dry Density (lbs/cu.ft)	Compressive Str. (psi)	Average Density	Average Strength	Core No.	Dry Density (lbs/cu.ft)	Compressive Str. (psi)
Ra-175	100.5	116					
Ra-176	98.9	82					
Ra-177	96.3	64					
Ra-178	106.2	128					
Ra-179	106.2	140					
Ra-180	105.0	94					
					No cores taken.		
Ra-181	114.8	273					
Ra-182	113.0	250					
Ra-183	112.0	220					
Ra-184	118.5	266					
Ra-185	117.5	300					
Ra-186	116.0	273					

LOCATION: Specimens - 1923+50 6' Rt.

DATE: September 23, 1959

Note: All values were plotted instead of averages because of wide scattering of points.

FIELD DENSITY-STRENGTH RELATIONSHIP - SUMMARY SHEET

RAVENSHAW PIT

PROCTOR SPECIMENS					CORES		
Specimen No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Density	Average Strength	Core No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)
Ra-199	96.8	105			RaC-200	112.5	156
Ra-200	97.7	105	96.5	105	RaC-202	114.6	174
Ra-201	95.4	105			RaC-204	117.5	156
Ra-202	103.1	186			RaC-206	114.0	173
Ra-203	102.2	165	102.5	165	RaC-208	115.3	111
Ra-204	101.8	140			RaC-210	112.0	111
Ra-205	109.9	236					
Ra-206	110.1	214	109.3	234			
Ra-207	108.0	220					
Ra-208	114.6	356					
Ra-209	114.0	294	114.0	316			
Ra-210	113.2	300					

LOCATION: Specimens - 1989+60 6' Lt.

Cores: -RaC-200 to 204 1989+60 6' Lt.

-RaC-206 to 210 2005+50 15' Lt.

DATE: September 26, 1959

Cement Content - 8.6%

FIELD DENSITY-STRENGTH RELATIONSHIP - SUMMARY SHEET

RAVENSHAW PIT

PROCTOR SPECIMENS					CORES		
Specimen No.	Dry Density (lbs/cu.ft)	Compressive Str. (psi)	Average Density	Average Strength	Core No.	Dry Density (lbs/cu.ft)	Compressive Str. (psi)
Ra-223	98.3	116			RaC-224	108.5	247
Ra-224	98.1	122	97.8	118	RaC-226	113.5	310
Ra-225	97.0	111			RaC-228	107.0	254
Ra-226	104.8	239			RaC-230	113.3	283
Ra-227	105.1	254	104.1	219	RaC-232	116.2	378
Ra-228	102.5	166			RaC-234	116.1	320
Ra-229	113.1	320					
Ra-230	111.6	320	111.5	301			
Ra-231	109.9	264					
Ra-232	117.6	400					
Ra-233	116.9	386	117.1	378			
Ra-234	116.9	348					

LOCATION: Specimens 1962+00 6' Rt.   Cores: - RaC-224 to 228 1962+00 6' Rt.

- RaC-230 to 234 1962+50 6' Rt.

DATE: September 29, 1959

Cement Content - 6.2%

FIELD DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

RAVENSHAW PIT

PROCTOR SPECIMENS					CORES		
Specimen No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Density	Average Strength	Core No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)
Ra-241	100.1	87			RaC-248	112.6	111
Ra-242	96.5	58			RaC-250	111.8	156
Ra-243	96.0	46			RaC-252	113.3	128
Ra-244	102.8	105					
Ra-245	102.4	100					
Ra-246	101.5	70					
Ra-247	111.0	210					
Ra-248	109.0	156					
Ra-249	108.1	---					
Ra-250	114.6	231					
Ra-251	113.7	161					
Ra-252	114.2	151					

LOCATION: Specimens - 2047+00 18' Rt. Cores - 2047+00 18' Rt.

DATE: October 17, 1959

Cement Content - 6.6%

FIELD DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

REAUME PIT

PROCTOR SPECIMENS					CORES		
Specimen No.	Dry Density (lbs/cu.ft)	Compressive Str. (psi)	Average Density	Average Strength	Core No.	Dry Density (lbs/cu.ft)	Compressive Str. (psi)
R-37	104.0	235			RC- 8	114.4	472
R-38	104.6	250	104.2	224	RC- 9	112.7	509
R-39	104.1	208			RC-10	111.3	590
R-40	111.1	320					
R-41	110.5	330	110.6	314			
R-42	110.2	296					
R-43	115.6	482					
R-44	115.6	454	115.6	462			
R-45	115.7	450					

LOCATION: Specimens - 1965+00 6' Rt. Cores - 1965+00 6' Rt.

DATE: July 28,1959

FIELD DENSITY-STRENGTH RELATIONSHIP - SUMMARY SHEET

REAUME PIT

PROCTOR SPECIMENS					CORES		
Specimen No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Density	Average Strength	Core No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)
R-50	102.0	274			RC-10	110.7	327
R-51	102.0	270			RC-11	113.1	344
R-52	107.6	414			RC-12	110.2	323
R-53	108.0	364			Rc-13	110.7	300
R-54	107.7	338			RC-14	113.2	315
R-55	109.5	452			RC-18	113.6	487
R-56	109.0	488			RC-19	113.9	506
R-57	109.4	502					
R-58	114.0	572					

LOCATION: Specimens 2031+50 18' Rt. Cores RC-10 to RC-14 2031+50 18' Rt.

DATE: July 29, 1959 RC-18 to RC-19 2060+00 18' Rt.

Note: All values were plotted instead of averages because of wide scattering of points

FIELD DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

REAUME PIT

PROCTOR SPECIMENS					CORES		
Specimen No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Density	Average Strength	Core No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)
R-61	101.8	272			RC-23	110.7	369
R-62	101.9	268	101.9	257	RC-24	111.8	368
R-63	101.9	235			RC-25	112.3	441
R-64	110.0	385			RC-26	113.2	437
R-65	110.2	458	109.5	412	RC-27	113.4	380
R-66	109.1	438					
R-67	112.7	420			RC-31	112.0	416
R-68	112.1	472	111.4	430	RC-32	113.0	447
R-69	111.5	395			RC-33	110.9	458
R-70	116.2	557					
R-71	115.7	596	115.5	568			
R-72	115.2	545					

LOCATION: Specimens - 2115+90 6' Lt. Cores - RC-23 to 27 2115+90 6'Lt.

DATE: July 30, 1959 - RC-31 to 33 2090+00 6'Lt.

FIELD DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

REAUME PIT

PROCTOR SPECIMENS					CORES		
Specimen No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Density	Average Strength	Core No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)
R-73	106.8	257			RC-37	112.3	396
R-74	105.2	257	☆ 105.2	☆ 250	RC-38	112.1	380
R-75	105.2	261			RC-39	111.4	353
R-76	110.3	420			RC-40	111.4	364
R-77	110.3	315	110.3	362	RC-44	109.5	280
R-78	110.3	354			RC-45	108.5	379
R-79	114.5	275			RC-46	109.0	352
R-80	115.2	545	☆☆ 115.4	☆☆ 448			
R-81	115.7	441					

LOCATION: Specimens - 2173+35 6' Lt. Cores - RC-37 to 40 2173+35 6' Lt.

- RC-44 to 46 2193+00 6' Lt.

DATE: July 31, 1959

☆ Average of R-74 and R-75

☆☆ Average of R-80 and R-81

FIELD DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

REAUME PIT

PROCTOR SPECIMENS					CORES		
Specimen No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Density	Average Strength	Core No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)
R-97	107.4	292					
R-98	104.0	211	103.3	212	RC-72	119.2	524
R-99	102.5	211			RC-73	117.3	410
R-100	112.9	420			RC-74	114.9	450
R-101	109.7	292	108.6	287	RC-64	113.5	338
R-102	108.9	275			RC-65	115.1	406
R-103	118.8	537			RC-66	114.7	432
R-104	113.9	401	114.3	412	RC-67		
R-105	115.8	424					
R-106	120.2	358					
R-107	117.9	476	118.4	506			
R-108A	118.9	410					

LOCATION: Specimens - 2174+00 18' Rt. Cores - RC-72 to 74 2174+00 18' Rt.

- RC-64 to 67 2154+85 6' Rt.

DATE: August 5, 1959

Note: Average values recorded were obtained from a curve fitted to all the points.

FIELD DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

REAUME PIT

PROCTOR SPECIMENS					CORES		
Specimen No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Density	Average Strength	Core No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)
R-117	99.5	212			RC-78	110.2	432
R-118	99.0	186			RC-79	110.2	475
R-119	101.0	186			RC-80	109.9	445
R-120	105.6	257			RC-81	110.1	458
R-121	104.4	212	107.5	200	RC-87	117.1	410
R-122	104.9	275			RC-85	111.3	314
R-123	110.9	420			RC-86	116.0	424
R-124	111.0	358	105.2	266			
R-125	110.8	318					
R-126	113.8	266					
R-127	114.5	344	112.9	347			
R-128	115.4	366					

LOCATION: Specimens - 2220+75 6' Rt. Cores - RC-78 to 81 2220+75 6' Rt.

- RC-85 to 87 2255+57 6' Rt.

DATE: August 6, 1959

Note: Average values recorded were obtained from a curve fitted to all the points.

FIELD DENSITY - STRENGTH RELATIONSHIP - SUMMARY SHEET

UPDIKE LAKE PIT

PROCTOR SPECIMENS					CORES		
Specimen No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Density	Average Strength	Core No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)
U- 6	95.2	86			UC-96	108.7	240
U- 7	97.6	96	96.4	88	UC-97	106.3	168
U- 8	96.5	80			UC-98	107.5	208
U- 9	103.5	150			UC-99	108.1	200
U-10	100.8	140	102.4	146	UC-94	109.7	240
U-11	100.7	96			UC-95	109.5	258
U-12	110.0	219					
U-13	107.1	196	* 107.0	* 192			
U-14	106.5	188					
U-15	111.8	266					
U-16	112.2	258	111.4	246			
U-17	110.2	222					

LOCATION: Specimens 2479+50 6'Lt. Cores - UC-96 to 98 2479+50 6' Lt.

DATE: September 4, 1959 - UC-94 to 99 2497+66 18' Lt.

Cement Content - 12.3% * Average of U-13 and U-14

FIELD DENSITY-STRENGTH RELATIONSHIP - SUMMARY SHEET

UPDIKE LAKE PIT

PROCTOR SPECIMENS					CORES		
Specimen No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Density	Average Strength	Core No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)
U-18	101.0	42			UC-100	110.9	220
U-19	102.1	60	101.5	46	UC-101	108.6	160
U-20	101.2	34			UC-102	107.0	176
U-21	106.6	97					
U-22	105.7	72	106.4	78			
U-23	106.8	64					
U-24	112.0	136					
U-25	111.6	103	111.6	122			
U-26	111.0	128					
U-27	115.8	102					
U-28	115.0	148	114.9	123			
U-29	113.9	117					

LOCATION: Specimens 2486+65 6' Rt. Cores 2486+65 6' Rt.

DATE: September 7, 1959

FIELD DENSITY-STRENGTH RELATIONSHIP - SUMMARY SHEET

UPDIKE LAKE PIT

PROCTOR SPECIMENS					CORES		
Specimen No.	Dry Density (lbs/cu.ft)	Compressive Str. (psi)	Average Density	Average Strength	Core No.	Dry Density (lbs/cu.ft)	Compressive Str. (psi)
U-30	97.2	62			UC-121	110.8	280
U-31	99.0	71	97.7	64	UC-122	110.5	252
U-32	96.8	61			UC-123	111.2	258
U-33	103.2	111			UC-124	110.7	262
U-34	102.5	93	102.4	99	UC-125	108.9	258
U-35	101.3	91			UC-126	107.8	314
U-36	108.9	174					
U-37	109.3	181	108.8	168			
U-38	108.4	152					
U-39	112.8	163					
U-40	112.8	209	113.2	190			
U-41	113.9	198					

LOCATION: Specimens 2586+00 6' Lt. Cores UC-121 to 123 2586+00 6' Lt.

UC-124 to 126 2555+95 18' Lt.

DATE: September 11, 1959

Cement Content - 9.9%

FIELD DENSITY-STRENGTH RELATIONSHIP - SUMMARY SHEET

UPDIKE LAKE PIT

PROCTOR SPECIMENS					CORES		
Specimen No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Density	Average Strength	Core No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)
U-42	97.8	89			UC-145	108.5	164
U-43	95.0	76	* 95.4	* 74	UC-146	103.2	146
U-44	95.8	75			UC-147	111.8	222
U-45	101.1	136			UC-148	111.2	244
U-46	97.5	100	** 98.5	** 100	UC-149	108.7	287
U-47	99.5	100			Uc-150	110.1	262
U-48	104.9	188					
U-49	104.4	184	*** 104.7	*** 184			
U-50	106.0	120					
U-51	111.7	258					
U-52	110.8	218	110.8	228			
U-53	109.6	207					

LOCATION: Specimens 2676+00 6' Lt. Cores UC-145 to 147 2676+00 6' Lt.

UC-148 to 150 2695+90 6' Lt.

DATE: September 16, 1959

Cement Content - 11.5%

* Average of U-43 and U-44
** Average of U-46 and U-47
*** Average of U-48 and U-49

FIELD DENSITY-STRENGTH RELATIONSHIP - SUMMARY SHEET

UPDIKE LAKE PIT

PROCTOR SPECIMENS					CORES		
Specimen No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Density	Average Strength	Core No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)
U-54	97.0	47			UC-158	111.2	92
U-55	98.0	44	98.4	43	UC-159	106.6	116
U-56	99.8	35			UC-160	108.9	134
U-57	102.8	65			UC-157	103.2	120
U-58	106.7	47	104.6	58	UC-154	105.8	150
U-59	104.4	61			UC-155	109.5	132
U-60	110.1	133					
U-61	109.8	95	109.8	105			
U-62	109.5	89					
U-63	112.8	150					
U-64	113.0	126	113.4	130			
U-65	113.8	113					

LOCATION: Specimens 2631+00 6' Rt. Cores 2631+00 6' Rt.

DATE: September 18, 1959

FIELD DENSITY-STRENGTH RELATIONSHIP - SUMMARY SHEET

UPDIKE LAKE PIT

PROCTOR SPECIMENS					CORES		
Specimen No.	Dry Density (lbs/cu.ft)	Compressive Str. (psi)	Average Density	Average Strength	Core No.	Dry Density (lbs/cu.ft)	Compressive Str. (psi)
U-66	97.5	127					
U-67	98.0	120	* 97.2	* 115			
U-68	97.0	102					
U-69	103.2	185					
U-70	102.6	123	** 101.8	** 174			
U-71	99.9	167				No cores taken	
U-72	108.0	272					
U-73	108.3	241	108.1	258			
U-74	108.0	259					
U-75	111.9	303					
U-76	111.1	312	111.0	312			
U-77	110.1	321					

LOCATION: Specimens 2748+00 10' Lt.

DATE: September 24, 1959

Cement Content - 16.6%

* Average of U-66 and U-68

** Average of U-69 and U-71

FIELD DENSITY-STRENGTH RELATIONSHIP - SUMMARY SHEET

UPDIKE LAKE PIT

PROCTOR SPECIMENS					CORES		
Specimen No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)	Average Density	Average Strength	Core No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)
U-78	103.2	88			UC-178	108.5	160
U-79	101.8	82	101.8	78	UC-179	108.3	124
U-80	100.4	64			UC-180	109.3	154
U-81	105.0	120			UC-181	107.3	142
U-82	106.0	124	104.8	120			
U-83	103.4	116					
U-84	111.6	232					
U-85	111.0	198	111.2	204			
U-86	111.4	182					
U-87	114.4	230					
U-88	113.8	242	114.0	240			
U-89	113.8	248					

LOCATION: 2763+00 6' Rt. Cores 2763+00 6' Rt.

DATE: October 1, 1959

ADDITIONAL CORES

RAVENSHAW PIT

Location	Core No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)
1809/20 18' Lt.	RaC-50	114.0	255
	RaC-52	114.4	316
	RaC-54	110.9	284
1819/00 18' Lt.	RaC-56	111.1	322
	RaC-58	112.6	290
	RaC-60	118.2	284
1908/75 18' Lt.	RaC-98	117.0	350
	RaC-100	115.8	350
	RaC-102	116.1	328
1924/50 18' Lt.	RaC-104	117.0	495
	RaC-106	116.7	384
	RaC-108	115.0	500
1743/00 6' Rt.	RaC-122	108.2	322
	RaC-124	111.0	300
	RaC-126	105.3	250
1755/00 18' Rt.	RaC-128	111.2	362
	RaC-130	110.8	418
	RaC-132	111.0	316
1819/50 18' Rt.	RaC-146	101.0	140
	RaC-148	102.0	176
	RaC-150	103.0	176
2029/00 18' Lt.	RaC-212	121.0	384
	RaC-214	121.0	362
	RaC-216	123.0	294
2841/65 6' Lt.	RaC-218	124.0	322
	RaC-220	125.0	226
	RaC-222	121.0	272
1984/00 6' Rt.	RaC-236	110.4	348
	RaC-238	110.4	178
	RaC-240	110.9	327

ADDITIONAL CORES

REAUME PIT

Location	Core No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)
1918/00 18' Rt.	RC- 5	113.6	352
	RC- 6	113.6	362
	RC- 7	113.9	326
2211/75 18' Lt.	RC-50	115.7	502
	RC-51	116.6	428
	RC-52	118.8	560
	RC-53	116.8	398
	RC-54	118.1	480
2242/00 6' Lt.	RC-58	113.8	336
	RC-59	114.0	362
	RC-60	115.0	326
2273/25 18' Lt.	RC-91	110.3	537
	RC-92	113.5	502
	RC-93	110.5	502
	RC-94	111.0	476
	RC-95	111.2	530

ADDITIONAL CORES

UPDIKE LAKE PIT

Location	Core No.	Dry Density (lbs/cu.ft)	Compressive Str.(psi)
2344/46 6' Rt.	UC- 52	110.3	212
	UC- 53	106.4	248
	UC- 54	111.2	252
2369/12 6' Lt.	UC- 58	104.1	258
	UC- 59	104.7	366
	UC- 60	105.3	292
2412/85 18' Lt.	UC- 64	113.4	424
	UC- 65	113.0	344
	UC- 66	114.2	532
2422/10 6' Lt.	UC- 70	113.7	292
	UC- 71	114.7	340
	UC- 72	110.3	371
2408/75 6' Rt.	UC- 76	109.8	252
	UC- 77	110.6	270
	UC- 78	109.5	328
2443/00 18' Lt.	UC- 82	109.9	389
	UC- 83	112.3	489
	UC- 84	113.0	340
2440/45	UC- 88	107.9	326
	UC- 89	106.5	353
	UC- 90	110.8	397
2528/80 18' Lt.	UC-106	111.1	230
	UC-107	114.6	252
	UC-108	111.6	230
2523/00 6' Lt.	UC-109	109.3	310
	UC-110	110.2	231
	UC-111	114.3	244
2519/60 6' Rt.	UC-115	108.1	230
	UC-116	108.9	137
	UC-117	108.6	122
2529/10 6' Rt.	UC-118	106.2	176
	UC-119	108.5	199
	UC-120	111.1	186

2552+52 18' Rt.	UC-127	107.6	292
	UC-128	111.4	358
	UC-129	105.0	284
2584+43 6' Rt.	UC-130	105.0	134
	UC-131	109.3	150
	UC-132	103.5	80
2612+82 18' Lt.	UC-136	107.1	194
	UC-137	109.3	168
	UC-138	106.5	168
2640+00 6' Lt.	UC-139	111.3	274
	UC-140	113.0	274
	UC-141	111.7	274
2711+91 18' Lt.	UC-151	113.6	98
	UC-152	106.1	150
	UC-153	109.7	128
2674+08 18' Rt.	UC-160	106.9	208
	UC-161	114.8	216
	UC-162	110.6	204
2697+10 6' Rt.	UC-163	110.4	200
	UC-164	112.1	275
	UC-165	116.3	208
2730+77 18' Rt.	UC-169	109.1	172
	UC-170	111.5	226
	UC-171	107.2	150
	UC-172	110.2	172
	UC-173	111.1	190
	UC-174	108.0	151

UNIFORMITY OF GRADATION

RAVENSHAW PIT

Location	Percent Finer Than 3/4	4	10	40	100	200	Uniformity Coefficient
1858/00	100	99	98	87	35	20	6
1882/25	100	100	99	95	50	24	5
1956/25	100	100	100	97	45	20	5
1884/00	100	100	100	94	30	20	6
1923/50	100	100	99	89	32	16	6
1989/60	100	100	99	95	37	19	6
1962/00	100	100	99	94	40	19	4
2047/00	100	99	97	79	25	16	7

Coefficient of Uniformity determined by extrapolation

SEGREGATION OF SANDSTONE PARTICLES

P-1

P-1

RESULT OF COMPACTION PLANES INTRODUCED DURING FINISHING

P-2

Left portion of roadway scarified during finishing
P-3

RESULT OF OVERLAPPING AT LONGITUDINAL JOINT

P-4

P-4

RESULT OF OVERLAPPING AT TRANSVERSE JOINT

P-5

P-5